Innovations and challenges of the energy transition in smart city districts

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Edited by
Sven Leonhardt, Tobias Nusser, Jürgen Görres,
Sven Rosinger, Gerhard Stryi-Hipp and Martin Eckhard

DE GRUYTER

ISBN 978-3-11-077754-3
e-ISBN (PDF) 978-3-11-077756-7
e-ISBN (EPUB) 978-3-11-077763-5
DOI https://doi.org/10.1515/9783110777567

Library of Congress Control Number: 2023938955

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the internet at http://dnb.dnb.de.

Cover image: metamorworks/iStock/Getty Images Plus
Typesetting: Integra Software Services Pvt. Ltd.
Printing and binding: CPI books GmbH, Leck

www.degruyter.com

Preface

Climate change represents one of the greatest challenges facing society in the 21st century: if greenhouse gas emissions are not effectively limited, the consequences of climate change will affect all areas of human life. The breach of international law due to the war of Russia against Ukraine and the corresponding geo-political consequences mean that the energy transition is becoming even more relevant. A climate-neutral energy system is also becoming increasingly important against the backdrop of a need for greater independence from fossil fuel imports while simultaneously ensuring a secure supply of electricity and heat.

The Paris Climate Agreement aims to limit the consequences of climate change and sets the goal of achieving a climate neutral world by 2050. Germany has set itself the goal of achieving this at national level by 2045 at the latest. The evaluation of the agreements which have been reached so far for the 2030 targets at the Climate Change Conference in Glasgow in 2021, made it clear that the measures to date are not sufficient to limit global warming to 1.5 degrees Celsius. Before the next Climate Change Conference in November 2022, further steps are necessary, particularly regarding the long-term strategy.

In its report "Net Zero by 2050", the International Energy Agency (IEA) defines requirements for the building, electricity, and heating sectors, including the requirements that all new buildings will comply with zero-carbon-ready building standards by 2030 and that emissions from electricity generation will fall to net zero by 2035. Given the long investment periods in the building and energy sectors, these are very ambitious goals – for Germany too.

An analysis of what has been achieved so far was released in the inaugural climate protection report of the German Federal Ministry for Economic Affairs and Climate Action and shows that development in the building sector and in the area of renewables has fallen short of expectations, especially in recent years. This is not only due to technical and economic reasons, but also to social barriers and obstacles to the transformation of urban structures.

With the funding announcement "Solar Building/Energy Efficient City", the former German Federal Ministry for Economic Affairs and Energy and the Federal Ministry of Education and Research took the initiative back in 2016. The focus of the funding initiative was the development and demonstration of forward-looking overall concepts for sustainable urban design at a practical level, with the full participation of the municipalities and the local population and consideration of the social, ecological, and economic aspects. Based on these criteria, the two Ministries agreed to fund six lighthouse projects.

These projects aimed to show how reduced energy consumption in urban districts is possible, how the efficient coupling of electricity, heat, and mobility can succeed and how the useful integration of renewables into the energy supply is viable. Funding of approximately € 105 million was invested in this long-term initiative for re-

https://doi.org/10.1515/9783110777567-202

search, development, and innovation covering six projects for sustainable urban development in Oldenburg, Kaiserslautern, Heide, Zwickau, Esslingen, Stuttgart, and Ueberlingen.

After many years of dedicated work by the six consortia, the most important findings of the practical scientific work in urban development have now been compiled in this book. The solutions presented here incorporate technical and economic as well as social aspects. The projects showcase sustainable solutions at urban district level, the potential efficacy of comprehensive measures and may even help imitators to avoid common mistakes. With the help of the findings and insights presented in this edited volume, selected solutions will hopefully contribute to accelerating urban climate protection.

Christian Maaß
Director General
Federal Ministry for Economic Affairs and Climate Action

Volker Rieke
Director General
Federal Ministry of Education and Research

Foreword of the Editors

The energy concept and the resolutions of the German government on the energy transition are important milestones for shaping the future energy system. Among other things, energy efficiency is to be increased to the extent that by 2050 only half of the primary energy consumption will be required compared to 2008.

In Germany, around 75% of people are living in cities. Cities and agglomerations are therefore special living, economic and cultural spaces. As such, they demand a sustainable energy system and must be designed to be highly energy efficient. The building sector is particularly relevant for increasing energy efficiency: residential and non-residential buildings nationwide consume around 35% of final energy, around three quarters of which is in the form of heat. The energy transition resolved by the German government, i.e., the restructuring of the German energy supply on the basis of high efficiency and with extensive use of renewable energies, can therefore only succeed if this transition is implemented not only in the electricity market but also in the heating market (so-called "heat transition"). In view of the energy and climate policy goal of a nearly climate-neutral building stock by 2050, renewable energies must be integrated to a much greater extent into the heating sector, in addition to increased energy efficiency. Due to their great leverage, cities and agglomerations offer the opportunity to put technological and social innovations into practice much more quickly and effectively, and thus to meet the German government's energy policy goals.

This book is intended to provide a framework for action for practitioners and scientists, and to highlight innovations, problem areas and creative approaches to solutions from the lighthouse projects of the Solar Building/Energy Efficient City funding initiative.

Approaches and results in the areas of energy systems, energy management, heat transition, hydrogen, acceptance, neighbourhood concepts, business models, mobility, participation, demonstrators . . . from the six lighthouse projects are highlighted and discussed:

- Es_West_P2G2P: Climate-neutral urban district „Neue Weststadt“
- QUARREE100: Resilient, integrated and system-serving energy supply systems in existing urban quarters with full integration of renewable energies – "Reallabor Rüsdorfer Kamp"
- ZED: Demonstrating Zwickau's Energy Transition
- ENaQ – Energetic Neighborhood Quarter
- PFAFF: Implementation of the real laboratory "PFAFF-Areal"
- STADTQUARTIER 2050 – Jointly solving our challenges

The anthology Innovations and challenges of the energy transition in smart city districts provides information on a variety of different topics dealing with the energy transition as well as the associated challenges in the transformation of cities and neighborhoods. The contributions represent the different perspectives of various ac-

https://doi.org/10.1515/9783110777567-203

tors from a wide range of industries, institutions and (scientific) disciplines. To give you, the reader, a rough orientation in classifying the chapters, they have been divided into two categories.

Science: These contributions have been prepared primarily from the perspective of science and research. They mostly deal with the theoretical foundations of the respective research topic and are predominantly based on a comprehensive literature review. As is not uncommon in the research area “energy transition”, the contributions nevertheless additionally deal with application-oriented solutions and thus also represent the reference to the respective lighthouse project.

Practice: These articles were written more with a focus on practical applications and often contain experience reports or best practice solutions from the study quarters and real world laboratories of the individual lighthouse projects. Discussions of (concrete) regulatory framework conditions or practical guidelines for the application of technologies or processes for specific institutions (e.g. municipalities, energy cooperatives, etc.) were also given this label.

Sven Leonhardt, Tobias Nusser, Jürgen Görres. Sven Rosinger,
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1 Introduction

'How can we make energy both clean and affordable?' asked *+3* magazine (https://plus-drei.de) in February 2022. Answers were provided by, among others, meteorologist Sven Plöger, who advocated 'getting rid of fossil fuels'. Economist Claudia Kemfert described 'the magic triangle of renewables, based on the three pillars of energy transition, electrification and efficiency'. In contrast, Axel Gedaschko, President of the German Housing Industry Association, argued for 'socially just solutions – instead of more and more demanding and expensive efficiency standards'. Finally, Lukas Köhler from the FDP parliamentary group in the German Bundestag also contributed to the discussion; his credo was 'open competition for the best CO_2-saving solutions'.

The Federal Ministry for Economic Affairs and Energy (now the Federal Ministry for Economic Affairs and Climate Action, or BMWK) and the Federal Ministry for Education and Research (BMBF) had announced a similar competition for the best ideas in April 2016: the funding initiative 'Solar Construction/Energy Efficient Towns'.[1] Here, too, the aim is to transform the energy supply towards environmentally friendly, safe and cost-effective energy. The call was for 'lighthouse projects in the form of living labs and comprehensive neighbourhood projects that pioneer an integrated energy concept from research to implementation with the involvement of all relevant stakeholders' (BMBF announcement of 23 April 2016). They explicitly welcomed 'experimental spaces' in which new technologies could be tested and institutional structures changed, but also where stakeholders could work together in new partnerships. In other words, they called for 'transformative research' (ibid.) with the aim of further developing established research approaches and testing out new ones.

This article is about the six winners of this call. A panel of experts selected them from more than 60 competing consortia. The key evaluation criteria were 'the level of scientific and technical innovation or risks', 'the professional competence of the partners, the participation of small and medium-sized enterprises (SMEs), a balanced and

1 https://www.fona.de/en/measures/funding-measures/funding-initiative-solar-construction.php (Accessed 09 June 2022).

Simon Moeller, **Michael Schneider**, Ludwig-Maximilians-Universität München
Sven Leonhardt, Westsächsische Hochschule Zwickau

https://doi.org/10.1515/9783110777567-205

binding cooperation between the partners involved', but projects were also assessed on 'the prospects of realising the project plan' and the 'scientific-technical and economic prospects of success', as well as the 'social significance' of the project (ibid.). Such a catalogue of evaluation criteria leads one to expect extraordinary things from the winners – as does the amount of funding on offer, around 100 million euros with which, in the period from 2017 to 2023, the six lighthouse projects are to demonstrate how 'urban districts successfully act as local drivers for the energy transition' (BMBF 2017).

To produce the 'transformative research' (WBGU 2011, Schneidewind/Singer-Brodowski 2014) postulated in the call for proposals, the consortia are not only faced with the task of developing innovative solutions to the concrete social problems of the energy transition at the district level together with (local) stakeholders, but also to provide proof of concept in the field, or at least demonstrate in principle the feasibility of particular concepts. Therefore, a prerequisite for (socio-technical) solutions to be both viable and accepted is the involvement of societal stakeholders in the research process: their expectations, experiences and know-how are brought together with scientific and technical knowledge – with the aim of ensuring that the results of the research process bring benefits for science and society alike.

The following sections describe to what extent the ministries' goal to generate 'socially robust knowledge' (Nowotny/Scott/Gibbons 2001) and to help shape social reality in living labs has succeeded after almost five years of funding. The second section describes the projects and their scope. The third section deals with how the projects typically unfolded and the delays and feedback loops that occurred. Sections 4 and 5 look at the central actors involved and the external conditions that had an impact on the projects. The last section asks to what extent the projects fulfil their claim to be 'lighthouse projects', and what the coordinators assess as the key findings from the initiatives. Put more systematically, and again from the logic of the transformative research process (cf. Schneidewind/Singer-Brodowski 2014, Jahn/Keil 2016), we ask:

- To what extent has it been possible – in the beginning of the projects – to 'construct' a common problem out of the different social perceptions and the academic descriptions of the problem and to combine it into a unified plan?
- Did the partners from practice and research succeed in jointly implementing a solution, and to what extent does this correspond to the goals they set?
- Which actors were particularly important to this process and what specific expectations, motivations and interests emerged, and to what extent were conflicts baked in as a result?
- To what extent was it necessary to adapt the plans due to existing and evolving conditions guiding decision-making within projects, and what barriers have emerged on the road to climate-neutral districts?
- Can the projects live up to their claim of being 'lighthouse projects' despite the repeated adaption of plans, and how do new, sometimes surprising, results contribute to their status as lighthouse projects?

Empirical studies, for example of 'smart grid experiments' (Lösch/Schneider 2017) or 'urban labs' (Scholl/de Kraker/Hoeflehner et al. 2018, Reusswig/Lass 2017), show that transformation processes by no means follow a simple, linear model – from problem construction to idea generation to implementation and knowledge transfer. Rather, they usually proceed in recursive loops, are characterised by numerous breaks and therefore resemble the 'fireworks model of innovation' (Van de Ven/Polley/Garud et al. 1999). That is, they are subject to non-linear dynamics, surprises are inevitable, and the process is therefore neither stable and predictable, nor random. We contend that innovations are unpredictable not because they are at the mercy of chance, but because they are subject to a complex interplay of all actors involved in the process. The course of such interactions therefore represents an experiment with an open outcome, both for the participants themselves and for any observers. We will refer to these findings throughout the article.

The empirical basis of the article consists of guided interviews with the coordinators of the six lighthouse projects, but also with other key actors, named by the coordinators, in order to gain even deeper insights into critical events, difficult underlying conditions or the parties involved in the project. A total of ten of such interviews were conducted; they lasted an average of 70 minutes, were recorded, transcribed and analysed with the methods of qualitative content analysis (Mayring 2008) using software tools (MAXQDA). In addition, the minutes of the meetings between the lighthouse projects were also included in the analysis; not only were (interim) results from all six lighthouse projects presented at these meetings, but workshops were also held on the topics of 'Technologies of regenerative energy supply', 'Regulatory challenges' or 'Participation in the living lab'.

2 The Six Lighthouse Projects

The two ministries expect the six lighthouse projects to address various energy-related and socio-economic questions from a systemic perspective – from basic research to technology development and implementation in living labs (announcement of 23 April 2016). Table 1 provides an overview of the project consortia, the amount of funding awarded, the size of the living labs and the central objectives of each project.

- The largest lighthouse project, with 21 collaborative partners, is 'ENaQ: Energetic District Quarter – Oldenburg Air Base'. The redevelopment consists of converting of one of Lower Saxony's largest former military sites to residential use, and a 3.9 ha area with about 110 residential units has been explicitly designated as a 'living laboratory' for testing new smart city concepts.
- Providing innovative solutions for a completely new district is also the goal of 'ES-West-P2GP: Neue Weststadt Esslingen': An innovative energy supply concept based around the use of an electrolyser for hydrogen generation and utilisation

of waste heat is being developed and implemented by 13 partners in an urban quarter with over 600 flats, office and commercial spaces.

– In Kaiserslautern, the 9 partners of ‘Living Lab Pfaff’ are showing how a climate-neutral urban quarter with new and listed buildings can be created from an industrial wasteland. The consortium aims to lay the foundations of an energy plan for a district of about 40 ha, with more than 40 buildings to be built. The concrete demonstration of use cases and the starting point of the energy infrastructure centres around two existing buildings and a living lab centre, where stakeholders can test and develop further innovations.
– In Stuttgart and Überlingen, 11 partners are working together on the project ‘STADTQUARTIER 2050’, which involves redeveloping two urban residential districts with a total of about 960 households in a socially responsible, climate-neutral way and transferring the concepts to other quarters. The plan is to use local district heating, supplied mostly from renewable sources, such as geothermal, wastewater, biomass and solar heating. In addition to the implementation of the energy plan, the project partners are working on technological issues such as developing four different tools that can be applied in other city districts as well. Furthermore, the whole process is supported by social research.
– The 20 collaborative partners on the ‘QUARREE 100’ lighthouse project are laying the foundations for the transformation of an existing district (‘Rüsdorfer Kamp’) with around 220 households into a sustainable district. Like in the other projects, the partners are focusing on several goals, such as power-to-X technologies, a district heating network, renewable energies and the integration of the heating, electricity and transport sectors.
– The lighthouse project ‘ZED: Zwickauer Energiewende Demonstrieren’ (Demonstrating (the) Zwickau Energy Transition) is seeking to create a ‘zero-emissions quarter’ incorporating existing buildings. 13 collaborative partners want to advance digitalisation in the energy supply network for around 800 households in the Zwickau-Marienthal living lab, with the aim of shaping the energy transition in a way that is acceptable to residents with the help of innovative (information) technologies and participatory formats.

These six lighthouse projects were selected in 2017 and represent a broad spectrum of different energy plans, energy carriers, installations or management systems in the respective living labs. All the lighthouse projects are seeking to show how energy consumption can be reduced in the individual urban districts, how the smart coupling of electricity, heat and transport can succeed, and how renewable energies can be integrated into the energy supply in a way that is acceptable to residents. In short: How

Table 1: The 6 lighthouse projects – amount of funding, partners, district size and central goals.

Lighthouse project	Amount of funding	Coordinator and number of partners	District size, Number of residential units	Central goals
Energetisches Nachbarschaftsquartier Fliegerhorst Odlenburg (www.enaq-fliegerhorst.de)	approx. 19.6 m €	**City of Oldenburg with OFFIS – Institute for Computer Science** 21 predominantly regional partners from business, research and municipal administration	3.9 ha, 110 residential units	Establishment of a Smart City test and trial field for: – Technical and non-technical innovations – Communal living projects – Innovative supply and transport concepts – Networking of industrial and R&D projects – Pilot projects bringing together stakeholders
Klimaneutrales Stadtquartier in Esslingen am Neckar (www.neue-weststadt.de/ klimaquartier)	approx. 12.5 m €	**Steinbeis Innovation Centre Energy, Building and Solar Technology** 13 partners from research, business and municipal administration	approx. 12 ha, 600 residential units	– Climate neutrality and local energy cycles – H_2-generation with waste heat utilisation in the district – Coupling the electricity, heating, cooling and transport sectors – Living lab: networking of agriculture, energy, transport, industry and buildings – - Accom -panying the transformation process through social science monitoring

(continued)

Table 1 (continued)

Lighthouse project	**Amount of funding**	**Coordinator and number of partners**	**District size, Number of residential units**	**Central goals**
PFAFF Reallabor *Innovationen für nachhaltige Stadtquartiere* *Erneuerbar. Effizient. Digital.* (www.pfaff-reallabor.de)	approx. 23 m €	**City of Kaiserslautern with Fraunhofer Institute for Solar Energy Systems** 9 network partners from research, business and municipal administration	approx. 19 ha, 423 residential units	Development and implementation of a climate-neutral district: – Innovative technologies (e.g. agent-based energy management, bidirectional charging of e-vehicles). – Dovetailing planning processes through new 3D city models or data exchange platforms – - Simulation of planning processes and monitoring tools
QUARREE 100 *Quartiersentwicklung mit 100% Regenerativer Energie* (www.quarree100.de)	approx. 24.4 m €	**Heide Region Development Agency** 20 partners from research, business and municipal administration	approx. 20 ha 200 residential units	Development of a post-war settlement into a model district: – Living and working (small businesses, home office) – Energetic refurbishment – H_2 and waste heat supply – System-serving, resilient energy concept in the district – Sector coupling (electricity, heat, transport) – - Plans to support multigenerational living

STADTQUARTIER 2050 – Herausforderungen gemeinsam lösen (www.stadtquartier2050.de)	approx. 13.5 m €	**State capital Stuttgart with Fraunhofer Institute for Building Physics (IBP)** 11 partners from research, business and municipal administration	approx. 4 ha (Stuttgart) approx. 5 ha (Überlingen) A total of 960 residential units	Climate-neutral energy supply of 2 districts, in Stuttgart (conversion of a former hospital site) and Überlingen (peripheral area redevelopment with building site expansion): – Direct use of local renewable energy sources – Greenhouse gas emissions from the energy sources used for building operation = 0 in annual balance (heat and electricity supply incl. user electricity) – - Socio-economy: Motivation of communities of apartment owners to participate in the district rehabilitation; development of a bonus system for conscious energy consumption; socially acceptable and rent-neutral renovation
Zwickauer Energiewende Demonstrieren (www.energiewende-zwickau.de)	approx. 16.1 m €	**City of Zwickau** 13 partners from research, business and municipal administration	approx. 5.6 ha, 800 housing units	Holistic innovations in the Zwickau-Marienthal district: – Development of electrical-thermal compound systems for zero-emission supply – Storage technologies for renewable energies and cross-trade ICT networking – Sector coupling of transport, electricity and heat – - Sustainable and user-oriented technology and district development

can urban districts become climate-neutral?[2] To this end, the consortia not only involved numerous actors from municipalities, the private sector, research institutes and civil society, but also developed a wide range of different modes of participation. These draw on a variety of methodological approaches, ranging from district apps and design-based solutions to simulations, gamification, usability tests, the establishment of living-lab centres and citizen science.

3 Project Progress

All six lighthouse projects address specific social and technological problems associated with the energy transition and aim to develop sustainable energy plans for the selected districts, as well as to test these solutions in a 'living lab' approach. By demonstrating the effectiveness of the concepts, the aim is also to show how districts can be made climate-neutral under the given conditions. Even though all the projects shared the same goal of sustainable district design, the specific starting conditions differed greatly.

3.1 Initial Conditions

> *We've been on this mission for a while, looking at how we get a handle on the issue of integrated energy transition in the region, because of course we're a real renewable surplus region, and all the citizens see wind turbines shut down day in and day out.*

The focus in the project to which this quotation relates was to use surpluses from the local generation of renewable energies and thereby address a problem that has been visible in the region for a long time. In another project, on the other hand, the goal was primarily to integrate an already existing proposal for a technological solution into a district whose planning was largely complete and thus to demonstrate the importance of the technology as a building block for climate-neutral districts:

> *The entire district is not the goal of this project now, the development of the district would have taken place in any case. It would also have taken place in a 'climate-neutral' way: via conventional methods with a combined heat and power plant and similar hardware. The new contribution that the municipality can make to the energy transition is this specific design for a renewable energy supply infrastructure.*

2 None of the projects had a definition of a 'zero-emission' or 'climate-neutral' district that could be used as a general standard. Because it probably was clear to most project partners from the very beginning that complete climate-neutrality could not be achieved within five years, the implicit goal was rather to reduce emissions as much as possible under the current conditions and with the means available, and with a strong focus on a sustainable heat and electricity supply.

Yet another project wanted to lay the foundation for the longer-term development of its' district by formulating a sustainable energy concept that linked to local authority plans to develop existing brownfield sites into sustainable districts.

> *We had already drawn up a master plan for 100% climate neutrality for the city. So there was a working context as a background. And the site had been lying fallow for a very long time and then there was a framework plan and efforts to create a development plan. At some point, the city and the environmental protection agency wanted to develop a sustainable district and talked to various actors to get an energy plan funded.*

In several cases, existing plans served as the impetus to seek funding to drive forward the development in question and to test innovative concepts. Thus, while some consortia were able to link up early on with an urban planning framework and therefore had the opportunity to help shape district development from the very beginning, in other cases the project itself provided the impetus for the city and the actors involved to address issues of sustainable district development in the first place.

> *And in this energy transition context, the university has already done a lot, together with different partners from the housing industry, but also from other areas. So, in principle, this project should take this topic to the next level. The idea was taken to the city, to the mayor and we were really kicking at an open door. And also the municipal companies, the housing company and the energy supplier, were very enthusiastic.*

In the example mentioned, the consortium came up with a completely new idea, for which a comprehensive plan had yet to be developed and a suitable district had yet to be found. The same was true in another case, where the consortium had a history of cooperation going back many years, but the project idea itself had its origin in the call for proposals.

> *We have a long-standing cooperation with the city, especially in various BMWi demonstration projects. It was certainly from this cooperation that the idea of taking part in the competition was born. Then we sat down together here and chose a district, or rather one was suggested to us by the city.*

3.2 Real Labs And Districts

Despite the differences in the specific starting conditions and although, from the very beginning, all the projects were pursuing the goal of designing sustainable districts, all participants soon realised that complete districts cannot be transformed within 5 years, especially when some of them occupy an area of up to 40 ha.

> *Today it is even more obvious to us that this implementation obviously needs a lot more time, but well, if you have five years, then you can't somehow do three months of research and the rest implementation, that's not possible either.*

District developments, in which many of the lighthouse projects are embedded, often take place over a period of much more than 10 years, from the first conceptual urban planning discussions and the architectural competitions, the definition of the development plans, and the ground-breaking ceremony to the completion of the development. Another thing the projects have in common, therefore, is that they are limited to more restricted demonstration cases – for example, by first designating a core area for which existing buildings are to be redesigned in such a way that the sustainable energy plan can be implemented. From these starting points, the plans would then launch the development of the wider district.

Thus, these demonstration cases are not to be dismantled after the end of the project period, as is often the case in research projects, but rather serve as a starting point for further development in the district or represent self-contained building blocks for sustainable energy supply in the districts. One of the goals of some projects is therefore to lay the groundwork for climate neutrality to become a central feature of future development in the districts by establishing relevant structures and specifications.

> *That's where we see ourselves, as having the task of developing and establishing this infrastructure, these formats, in order to establish a breeding ground for further research projects (. . .). So this development of the living lab, but not the development of the energy transition, that was a second very large component of our project, yes.*

3.3 Developing a Common Understanding of the Problem

In addition to the different starting conditions of the various lighthouse projects, different expectations and interests on the part of the project partners and stakeholders came to light, often early on in the project, which were not always adequately addressed and communicated. Such disagreements often begin with the description of the problem and the definition of common goals. Even if all stakeholders roughly agree on sustainable district development as a common goal and commit to a specific formulation of the problem in the project proposal, in many cases, the various actors first had to develop a common understanding of the problem after the start of the project.

> *Because if you are completely honest, the first year is a search for a common understanding, where arguments are exchanged, partners are motivated, ideas are generated, and then a plan is created.*

At the beginning of the project, generating a common understanding that everyone could support was necessary simply because the research proposal was often pushed forward by a single research partner. This partner then looked for other collaborators, including the relevant partners from the municipality, civil society and business. However, these partners from practice would often not have had a precise idea of what they were actually facing.

> *We had to work several night shifts to get this project up and running in such a tight timeframe. The city was not particularly involved at this stage. The coordinator did all that. And then all of a sudden the city was there: 'We now have jobs, okay, now we'll take a look at the project.'*

After the start of the project, therefore, there was often an increased need for communication and a period of orientation.

> *We also spent the entire first two years creating a level of communication where the different partners could talk to each other properly – not just the partners from research and business, but sometimes those from business sector A and business sector B as well. That's a huge point, but in my view these kinds of research projects are very, very well suited for this, because they make the risk manageable and give all the participants at least some opportunities to deal with such things independently of their usual capacities.*

The high need for communication was due in particular to the different experiences and working cultures that the project suddenly brought together.

In one project, the differences between the partners were so pronounced that the city would have preferred to start implementation immediately, while the research partners had to insist on developing plans before proceeding to implementation.

> *At the city's insistence, we decided on the concept much earlier, after about a year. We actually wanted to develop a concept from the different clusters over two years, bring them together and discuss them, and then make a decision. But we scaled that down, because there was such strong potential for conflict with the city and other actors, because they wanted to go straight to implementation. Their attitude was: we'll build something there and implement it and then we're done. You do some research.*

In order to develop a common understanding of the problem space, differences in ways of thinking and acting, as well as in forms of communication, must first be bridged in order to mediate between the different expectations of the project and the further process.

3.4 From Understanding the Problem to Developing the Plan

At the beginning, the core of all projects consisted of the development of a basic energy plan – often for the entire district, whose overall development extended far beyond the actual project duration. An initial implementation and demonstration of the feasibility of the concepts was, in most cases, supposed to be carried out at least in a core area of the district and for either some of the existing buildings or a smaller number of buildings that had yet to be constructed. This approach was intended not only to demonstrate the basic building blocks of sustainable district development by using the buildings as models, but also to enable the active involvement (participation) of residents in district development. The idea was to develop and test various modes of participation, community district design or digital housing services together with residents. In addition to some core actors who were necessary for the development of the energy plan, other partners with expertise in community research and development were also involved from the beginning.

As part of the energy plan and in addition to the solarisation of the buildings in the core area, all projects also developed a proposal for some kind of central supply or transfer station and a district heating network, the implementation of which was to begin during the course of the project. Because heat represents the largest proportion of the total final energy consumption in residential areas, the transformation of the heat supply is of great importance for sustainable development. Therefore, from the beginning, the focus of the projects was on energy sector integration (sector coupling) in order to ensure a sustainable heat supply:

> *The focus is of course on heat. That is not surprising, because heat is the main energy driver in a district. Even if we have also looked at transport and electricity consumption, you can see that heat is still the big energy driver in districts. Now, how do I find solutions that meet this demand to move towards CO_2 neutrality, or at least build a path towards it?*

Accordingly, in four of the projects, the consortia had the idea of extending the basic concept of a central supply or transfer station and a district heating network – alongside solarisation and increasing the energy efficiency of the buildings in accordance with the plans developed – to the entire district. For example, some partners, together with the participating municipalities, succeeded in introducing criteria into the development plans or purchase agreements with future investors that are designed to ensure the sustainable development of the district beyond the project period. Alternatively, others were able to implement an obligation for compulsory connection and usage for the heating networks.

More than half of the projects also show that one should not be too narrow-minded when defining the district boundaries. In the professional community, it has often been said that if a city is to successfully transition towards a sustainable energy supply, it is no longer sufficient to look at individual buildings, but instead districts should be considered as a whole. This basic idea of a district approach was also incorporated in the 'Gebäudeenergiegesetz' of 2020 (Deutscher Bundestag 2020). Yet the projects additionally show that a consideration of districts alone is sometimes not sufficient to develop sustainable solutions. Instead, in the course of the projects, the consortia often resorted to structures outside the district to ensure the viability of the energy plans. This included, for example, extending the boundaries of the search for consumers of the hydrogen produced, suppliers of industrial waste heat, or existing district heating networks that one could connect to outside the district.

> *Fortunately, here, it isn't like it is in urban development funding. There, you designate a district and it is very strictly defined. And you're only allowed to do things within the defined boundaries. We have a major client a little outside of here, who has signalled that he wants to join us. That is very important for us. At this point, we need an anchor customer, who has a relatively high demand. We once said that we need at least a 30 percent connection rate at the beginning, before investing actually starts.*

This extension of the search for producers or consumers of energy outside the district can not only help to guarantee minimum connection rates and thus ensure the economic viability of the proposed solutions, but also to enhance the sustainability of the development plans.

> *We did the energy plan, analysed the heat supply and came to the conclusion that using the industrial waste heat from a site that is in the immediate vicinity, but still four hundred metres away, would be the most ecologically and economically favourable option to realise the whole thing.*

Nevertheless, economic efficiency is the main motivation to look for connecting points in the wider environment, i.e. connections to existing infrastructures as well as synergies with entities outside the defined project area. In order for investments to be feasible, the infrastructure that exists within the framework of such projects must be connected to the larger system of energy supply and demand. In a broader sense, this is also described by some interviewees as the need for the developed solutions to serve the system or the grid.

> *Rather, the aim was to create this system that connects to and serves the wider energy system, and that is actually something that later turned out to be extremely complex, even from a purely legal point of view – how do you link it to the wider supply system?*

In principle, the interviews showed that three elements are essential for all the projects' district plans to ensure they meet the demand for sustainable supply structures. Firstly, it is important to ensure a certain building efficiency standard so that the heat generated is sufficient to meet demand. Secondly, it is necessary to tap into all local energy sources as completely as possible, e.g. by using available sources of waste heat or geothermal energy and completely solarising the roofs to provide enough green electricity for household use or for the heat supply. And thirdly, there is a need for cross-sectoral thinking, wherein the coupling of electricity and heat is ensured in most cases via various generators such as heat pumps, or via the use of waste heat from other plants and distribution through a district heating network.

> *In terms of learning from these approaches with the goal of climate neutrality, there are three or four simple truths. A first key element is solarisation, with photovoltaics as a basis. Then we need buildings with a good thermal insulation standard (. . .), in order to get the renewable energies into the buildings to a sufficient extent. Because environmental heat or renewable energies are only available to a limited extent in districts, demand must be correspondingly low. And then I have to use synergies by taking a cross-sectoral approach. That is also something that applies in general. (. . .) What does heat and electricity supply look like? How can I integrate the topic of transport? And can I create added value beyond that? And if we look at all sectors, then the energy sector and industry are also involved. That's why we say: 'This holistic thinking ultimately has to include all sectors.'*

A fourth component in almost all the projects is the provision of storage capacity for energy, be it in the form of electrolysers or battery storage. For the moment, building up storage capacity is currently only a small aspect of most projects, in part because there are not enough surpluses generated in the districts themselves that could be stored, and in part because there are regulatory and economic hurdles to the efficient storage of renewable energy generated at other locations. Therefore, the question of how well the local energy infrastructures can serve the efficiency of the whole grid becomes an issue again.

These basic elements of the energy plan can be found in some form in all projects and were therefore referred to as the "three or four simple truths" that can ensure the transferability of the results to other districts. In many projects, plans for transport, district apps and a variety of participation formats are included alongside the energy plans.

3.5 From Concept to Implementation

Initially, most actors seem to assume that after a prolonged concept phase for the development of the energy supply structures, an implementation phase will follow in a strictly linear sequence. While in the concept phase, the actors develop solutions, for which, among other things, they have to gather information, convince external actors (such as the city council or possible operating companies) and initiate approval procedures; once a final decision is made, 'only' the implementation itself remains. Implementation then 'only' means that previously developed concepts are built and thereby demonstrated in previously defined core areas. Most coordinators, therefore, had firmly expected a more research-oriented concept phase of usually two to three years at the beginning, after which the projects would go into implementation.

In fact, however, all the projects show that considerable difficulties arise during this process and that the ensuing course is anything but linear, especially when it comes to moving from concept development to implementation. Instead of a linear sequence, there are always feedback loops and redefinitions. Partners drop out partway through, or change their role because the direction the concept development has taken does not fit with their own ideas. Particular difficulties have arisen for the energy suppliers originally envisaged as operators of the energy systems and involved as project partners. In four of the six lighthouse projects, the original energy supplier has left the consortium or has relinquished the role of operator.

> *We probably had a very special case in our project. We started in 2017 with the same team as now, except for the one exception that we had this company with us for the operation and planning of the system. They left after about a year. There were certainly staff shortages or deficiencies, which is why they had difficulties with the planning and coordination with the small team. And on the other hand, I think they had other internal specifications or ideas for the systems, so they pulled the plug. Because we focused very strongly on the operation of this specific system, this could of course have been the downfall of our entire project.*

Such a change can be quite threatening for the whole project and leads to significant delays even where the partners are able to successfully adapt. When partners drop out, a new operator has to be found within a relatively short time if the remaining partners are to have any chance at all of implementing the plans. This happened in half of the projects. Some took steps to establish new operating companies for this purpose, while in others, the decision is still pending.

> *It's not quite as trivial as you might think. Because first of all, until such a municipal company is actually founded (which involves municipal supervision and everything that goes along with that – it's a very big process), it is not easy. The second thing is that not everyone is on board and behind us.*

In addition to the extreme case of a partner pulling out, the project partners also faced a variety of hurdles in trying to get their concepts implemented that they could not have foreseen at the beginning. These included regulatory challenges (for example, in the establishment of a 'customer system'), economic barriers that resulted primarily from competition with existing, conventionally operated supply systems, or environmental problems such as soil contamination. The concepts therefore had to be tailored to the specific conditions that prevailed in the local area, which is perhaps why the concept as originally envisaged turned out not to be feasible:

> *So the core objective of the application is: How can I supply the district with 100 per cent renewable energy from the region? We can already say that we have failed. We have a concept, but we haven't actually managed to achieve our goal of using the power from wind farms that would otherwise be switched off. Because the regulatory system, as it still is today, makes it impossible for me to use the electricity that is switched off five kilometres away in such a way that you can make it viable economically.*

Often, the research partners only realise in the course of putting the project plans into action, after working on a topic for some time, that the implementation is harder than initially thought. Delays also occur due to unforeseen barriers. A good example is the contamination of soils, the negative effects of which were additionally exacerbated in one case due to restrictions on gathering introduced during the COVID-19 pandemic.

> *Apart from that, we are currently having a hard time building up the area as a living lab, because the development is just so far behind the plan. We underestimated this unexploded ordnance clearance (UXO), especially in connection with Corona. UXO, assembly bans – what do you do if you find unexploded ordnance? So it had to be suspended completely, because then you can't get people together in a hall somewhere. Therefore, the exploratory work was stopped for about half a year. Then there were other contaminants in the existing buildings, so more of the existing buildings were demolished and more new construction was planned.*

Major social developments and crises can also cause hardship for projects that are scheduled to be completed within a certain period of time.

> *A large number of the buildings were to be demolished and redeveloped. But along the way, planning had to adapt to changing conditions. For example, the need for social housing keeps increasing, the school enrolment date changed mid-project which led to the need for more kindergartens.*

> *The refugee crisis in 2015 led to the need for interim accommodation, which was in part found in the site we are working on.*

In other cases, however, social developments can also have positive effects by providing important support for the partners.

> *Of course – this is one of the general conditions – the climate situation has changed in the last five years. That helps with participation, where people suddenly have more understanding of why such solutions are needed. It helps when comparing the price of heat, i.e. the developments of the last six months.*

Due to a stronger environmental movement and, more recently, sharply increased gas prices, concepts can become attractive when they were not before and thus give the projects additional impetus. In the course of time and as the project progresses, it can happen that external conditions change or are assessed differently and can thus have positive, as well as negative, effects. In extreme cases, as in one project, it can even happen that a partner who had previously dropped out rejoins the project.

> *And in the meantime, it turns out that the power supply company, which had left the project, is now interested in building a low-temperature heating network in the district and in fact is wiling to do this. It's partly because there was a change in the board of directors – it always depends on people. So at least we have achieved that.*

While such external developments are taking place, actors are constantly searching for solutions, continuing to develop the concepts, and rethinking or recomposing them in other ways.

> *When we started, we wanted to realise this hydrogen utilisation, either through a station for trailer filling, in order to bring the hydrogen from there to the industrial customers with trucks, or through a hydrogen filling station. However, a filling station is not economically viable at all because of the demand situation, even when considering the subsidies. And as far as the industrial supply is concerned, we started out with the aim of accommodating this plant technology in a new showcase district. There were many difficulties and challenges involved in doing this in a way that interfered as little as possible with the exterior design, which is why we had to refine or change the conceptual approaches, and which is why this filling station does not exist now. But of course we are still looking for solutions.*

In the end, the success of a project depends largely on whether the various actors involved in it can succeed in developing a basis of trust, cooperation and common objectives within the context of the diverse feedback processes that primarily take place between the idea generation phase, the decision-making phase and the implementation phase. And it also depends on whether the actors can enforce these concepts in light of the intricacies and uncertainties of the given conditions. In Sections 4 and 5, we look in more detail both at the actors who are indispensable for this process from the point of view of the interviewees and at the decisive internal and external conditions. The next subsection briefly recapitulates from a temporal perspective what the essential key points of the projects are and what the projects have in common in terms of content and organisation.

3.6 Temporal Dimension

Almost all the projects needed more time than was originally estimated (at least 6–7 years instead of 5 years) in order to be able to implement at least the main features of the project envisaged in the project proposal. All coordinators agree that the complete (re)development of a district is not feasible in such a short time.

> *I mean, we all know that the limited duration of these research projects is not sufficient to follow a district from the conceptualisation and planning stages, through the implementation and then to the monitoring phase. That is too short a time.*

It is precisely this temporal dimension – i.e. the differences between long-term district development, which can extend well over a decade, and the comparatively short project durations of five years – that repeatedly gives rise to difficulties in the course of the project. In particular, the implementation phase causes the greatest difficulties for the consortia and most often forces them to repeatedly jump back to earlier phases ('feedback loops').

> *At the beginning, it went pretty well and things also pretty much followed the timetable that had been set. With respect to two or three aspects of the project, maybe even a little faster. However, particularly when it came to the switch from research and concept development to implementation, that's where it suddenly becomes difficult (. . .). Some researchers don't necessarily realise what implementation means. The people in charge of implementation don't know what research is.*

All the projects face a synchronisation problem, regardless of where they stand with respect to further district planning: in order to significantly advance the planning for the wider district and possibly, as has happened in many projects, to be able to also define standard requirements for development plans and purchase contracts, the projects must start early in the planning process. This, however, makes it less likely that implementation will be completed within the timeframe of the project.

The more the actors focus on establishing an energy plan for the whole district, the more important it becomes to be able to contribute to the development of the building plans – and the more difficult it will be to finish the implementation within the time allotted to the projects, let alone to carry out an evaluation of the infrastructure implemented.

> *The timeline is a very decisive one and dealing with it is also a major problem in such projects. On the one hand, energy plans should be prepared as early as possible because they are related to urban land use planning and the development of the zoning plan. The project therefore started relatively early in relation to the overall district development. (. . .) Furthermore, everyone who does district development knows that first you have a development plan, then the plots have to be put*

out to tender, and then it takes several years until the building actually takes place. So it was absolutely clear that the realisation of the wider district development plan was not going to be possible within the framework of the project.

Conversely, when planning is already at an advanced stage and many decisions have already been made, this makes it difficult for the lighthouse projects to influence the design of the district and, at the same time, to accommodate major technological innovations in the district.

So the problems that gave us the biggest headaches were actually always due to the fact that everything was already planned and set in stone.

However, at the other extreme – namely when the impetus for sustainable district planning essentially came from the project itself and there was no larger plan for the development of the district that the project could slot into – things were not necessarily any easier for the actors. This is particularly the case in projects located in existing districts. Here, the key actors must be convinced of the necessity of a redesign and persuaded to shift the priorities of the district development to align with the goals of the lighthouse projects in the first place.

This overarching theme, which we are now also always hearing about on a supra-regional level, i.e. CO_2 neutrality and climate issues, is also relevant on a small scale, but more for the end users. And for the municipality, for research, where this was at the top of the agenda. But for the companies that actually implement it in the end, that also pay for it, that finance it, one simply has to say that there are other priorities at the top.

This synchronisation problem is also due to the fact that business partners, who are entrusted with implementation, e.g. investors, housing companies or power supply companies, do not usually base their time planning on research requirements and the duration of the concept development.

You can't take it for granted that when you suddenly come up with something like this, the investor will go along with it. They said, 'We'll do anything you want. The only restriction is that we won't wait for you. We have a fixed schedule. We have to deliver to our owners.'

However, despite all these obstacles, the long duration of the projects seems to be conducive to their success, as it allows for an intensive examination of the concepts. On the one hand, the public perception of the projects and the participation of the municipalities create pressure to deal with the issues and not to reject the proposed ideas lightly. On the other hand, the projects create the opportunity for plans to be worked on intensively and repeatedly and for alternative options to be considered – a procedure that would, under different circumstances, likely not happen due to the material and time requirements in normal everyday life.

Constant dripping wears the stone and we tried out a lot of things. Solutions were always looked at and corrected. (. . .) And that's why we needed this initial year, and although we were already known in the consortium and there were lots of connections with each other, it still tookone and a *half years to get there, to really work constructively with each other. A few partners held back a bit and could have been much more involved, they could have implemented much more if they had simply been more open from the beginning. But all in all, I think that with the compromise we reached there is something in it for everyone.*

4 Actors and Key Influencing Factors

All six lighthouse projects involve a large number of actors from municipalities, the private sector, research or civil society who had quite different motives, expectations and interests. However, according to the interviewees, some actors are particularly 'critical to success'. If the consortia do not succeed in seeing that the interests of these critical stakeholders are safeguarded, or if these stakeholders are not prepared to support the implementation or even leave the consortium altogether, the success of the projects is seriously at risk. This also explains why the interviewees focus on the creation and implementation of sustainable energy concepts and why topics such as participation, mobility services and other components of the projects often only play a secondary role in the interviews. In the following, the most important actors, and especially their motives and interests, their behaviour and their competences, will be discussed. First, however, we will discuss the fundamental differences between research and practice and social dynamics in the transdisciplinary process.

4.1 Research and Practice

Most interviewees make a fundamental distinction between research partners and partners from practice such as municipal or industry partners as well as civil society actors in terms of their respective roles in the project, their expectations and behaviours, and, last but not least, their goals. Nevertheless, it is rather unusual in district development for cooperation between research and practice in the consortia to be relatively close.

Normally, there aren't any discussions between researchers and practitioners. Usually, an investor talks to an engineering office or a planner, who then have a different argumentation. In the project, however, we noticed a big discrepancy in the communication between research partners and partners from practice, and there are not only investors to think about, but also the city administration, city planning, the power supply company, etc. It's a different language. It's a different approach. And above all, I would say that there is a big difference: for an investor or for a city administration, at some point, a development plan must be available or the investment decision must be made. So it's about delivering a product.

In order to establish a common understanding between partners with such divergent perspectives, there seems to be a considerable need for communication and reflection on their respective roles and expectations. However, some interviewees are not convinced whether it should be part of the researcher's role to convince practitioners of the validity of their concepts, and how much distance they themselves should have from objectives such as sustainability. Some interviewees tended towards a position where researchers neutrally develop concepts and are as unbiased as possible. They then repeatedly emphasise different perspectives on, and aspects of, a project to the practitioners so that the latter can make a sensible and sustainable decision.

> *Researchers have a bit of a role to play in presenting the breadth of innovative concepts. To remind the business partners of the concepts that exist and of the fact that it is important to be aware that the projects touch on different aspects, aspects that we as scientists are relatively impartial about because we bear little responsibility and few risks afterwards. In other words, if someone is only looking at the economy, then we have to say that there are other things, such as regulation. Or we have to look at the ecology or the social component.*

With these mentions of researchers' (supposed) impartiality and the differences in attribution of responsibility between researchers and business partners, the interviewee describes important reasons why participants have different perspectives and behaviour patterns: because it is the business partners who ultimately have to bear risks, and if the new solutions fail technically or do not pay off financially, they have to take responsibility for it. In contrast, it seems rather easy for the research partners to push for the implementation of more far-reaching measures – without bearing any entrepreneurial risks themselves.

> *At the end of the day, we as researchers come up with more or less innovative concepts, and ultimately a mayor or a city council or an investor has to decide what to do with them.*

Such differences are also reflected in the actors' expectations and assessments. For example, what a industry partner may judge as a highly innovative solution, may not even correspond to 'standard technology' for a research partner. Bringing together such different perspectives and linking them to a common solution is therefore at the core of the projects. Several interviewees think that it is precisely the 'scientist's distance from practice' that is decisive, by allowing for the development of concepts that go far beyond the status quo. Partners from practice, on the other hand, shy away from 'the risk of the new' and therefore often prefer to resort to familiar and tried-and-tested solutions.

In order to resolve this dilemma, according to most of the interviewees, the research partners in the living lab projects could not simply be neutral, but would also have to have an interest in the implementation of the concepts and therefore give up their 'distance' to a certain extent. The researchers had to engage with the interests and needs of the practitioners and also adopt a communicative attitude appropriate to transdisciplinary cooperation:

> *When a researcher gets involved in a living lab project, he must also have a stake in it and be prepared to work to ensure that what he develops tastes good to the fish and not just to the angler who hooks the result."*

While practitioners are required to be open-minded to new solutions, researchers have to strike a balance between being too close to practice and their professional distance from the project. Overall, the practitioners seem to be much more reserved about the objectives, while their participation in the projects seems to be essentially shaped by their specific (business) interests. From the coordinators' point of view, the practitioners therefore need more motivation to get involved and to commit to the objectives.

> *"And this thinking simply has to be there, the willingness to also think about what it means to take part in such a project: What am I getting myself into? Am I prepared to deal with new solutions? Of course, there are always risks involved. The question of legal issues. The question of commitment, the question of funding. Who bears the additional costs? How much acceptance is there, etc.?*

In particular, the prioritisation of different objectives, some of which were not openly formulated at the beginning of the projects, reflects the different attitudes of partners from research and partners from practice. While all actors agree that the security of the energy supply has the highest priority, they differ quite a bit in their assessments of other objectives. For the research partners, the lighthouse projects are primarily about new integrated solutions for districts that are as climate-neutral as possible. Aspects such as economic efficiency or 'warm rent neutrality' (meaning that rents including heating cost should stay the same after investments in energy efficiency or renewable energy supply) are important, but the decisive factor is that the solution is in line with the objective of climate-neutral supply, even if this means that energy prices have to increase or that less profit can be made compared to conventional solutions. However, partners from practice look at this differently; they expect the new energy concepts not to result in higher overall costs for housing and energy for the residents. In addition to their margins and return on investment, it is precisely this aspect that investors give priority to over climate neutrality. From this point of view, a new energy concept may well save less CO_2 if the rent including heating costs and potential returns remain the same.

> *After some time, we realised that we had not defined these goals clearly, neither among the project partners nor in discussions with the city or the municipal utility companies. And that naturally leads to the fact that if I have the goal of realising a climate-neutral district, and I then find out in the calculations that the heating price cannot remain at the usual heating price, but that a surcharge is necessary, then you have to go with it. But if at the same time you set another goal, that heating must not get more expensive, then I might have to say that that goal is not achievable.*

Such different logics and quite diffuse definitions of goals not only determine the actions of those involved, but, according to the interviewees, permanently become an issue within each project and have to be bridged again and again.

> *The goals that may be at the top of the list for researchers and also for the municipality are of course in the end not the top priority for the investors, who are also somewhat entrenched in their established models of thinking.*

In fact, industry partners prioritise the financial viability and economic efficiency of the developed solutions over sustainability, thus remaining oriented towards the current external conditions – current energy prices, their customers' demands and expectations, as well as existing technological concepts. From most coordinators' point of view, this perspective is strongly rooted in the status quo and lacks a longer-term orientation towards climate goals, legal and social developments and technological trends (including energy price developments). Conversely, practitioners often do not understand the disciplinary 'blindness' of the research partners and the large amount of time needed to develop the plans. Therefore, the researchers have to defend themselves against the impression that their proposals are too far removed from practice and cannot be implemented in reality.

4.2 Cities

One, if not the most essential, actor in all the lighthouse projects is the municipality itself, with its different political bodies and organs such as the environmental department, urban planning or licensing authorities. Therefore, it does not speak with one voice, and within the municipality, there are many different groupings with different agendas:

> *When you talk about the city, the question, of course, is who are you actually talking about? There is the environmental department, which manages the project, the urban planning department, which is responsible for the development of the land-use plan, and the mayor, who is ultimately responsible for everything. Then there is also the development company as a project developer and subsidiary, which acts independently. This means that when you talk about the city, you have to look closely at who it actually is, because of course there are also different opinions and attitudes within the city and its subsidiaries. As a result, you have to look carefully who you are talking to about what.*

In addition to the environmental departments, which are responsible for project coordination and/or public relations in more than half of the projects, the political structures, and in particular the mayor and the city council as central political bodies, play an essential role in the progress of the project. Mayors can achieve a lot through their prominent position and their generally good networking and can support the project considerably when it comes to clearing obstacles out of the way:

> *In the end, it is always a matter of political or public discussions. What counts, of course, are decisions. And so far, of course, after intensive preparatory work, they have always been initiated and adopted in the sense that we had proposed. From that point of view, there has always been support, both from the mayor and from the city council as a whole.*

Such support can make it much easier to solve problems – for example, if other actors are fundamentally opposed to implementation plans. Good networking and deep-rooted support from the city authorities is therefore a plus point in the implementation of these projects. In addition to the mayor, the municipal council also plays a significant role. The city council not only decides on development plans and purchase contracts – e.g. the topics of compulsory connection and the use of heating networks, or the decision about the solarisation of roofs – it also determines other political guidelines and guiding principles. Thus, the municipal councils also give the projects important political backing in negotiations with other administrative bodies or municipal subsidiaries.

> *The different departments can sometimes be a challenge, as different departments have different tasks or topics as their responsibility. For example, even when the environmental department sets high goals for energy efficiency, other departments might recoil and hesitate to prescribe high efficiency standards for investors, as they fear that they then won't find anyone who is willing to invest. The education authority, for example, has the job of providing education for children, the wastewater treatment plant has the job of cleaning the water. That's their primary objective, and energy reduction comes second. Similar things happened in our project and it was sometimes difficult to reconcile the different objectives (fresh air corridors, urban green spaces, noise protection, etc).*

The support of the city council must therefore be taken into account as an essential factor in such projects, even if its presence or absence is difficult to influence, and the city council should therefore, according to many interviewees, ideally be involved at an early stage and regularly informed about the progress of the project.

Since departments such as urban planning or the office responsible for building regulations, which are also needed for approvals and have to make project-relevant decisions at many points, are usually not directly represented in the project itself, fundamental political decisions can therefore make negotiations much easier.

4.3 Housing Associations

In addition to the political and administrative levels of the municipality, it is primarily the energy suppliers and the housing associations that are essentially responsible for the implementation of the projects. In most of the lighthouse projects, these actors are also fully or partially municipal companies. The question of what energy supply in general, and a secure and sustainable energy supply in particular, may cost, and thus the question of whether – and if so, in what form – it will be implemented in the projects, is decided to a large extent by these actors.

> *It is still the local actors that need to be involved as much as possible. I think that's important, whether it's housing associations or, very importantly, the municipal utilities with their focus on energy. If you meet with resistance from them, then it is very, very difficult. But if they are taken on board at an early stage and perhaps even won over as operators of parts of the project, then at least – often because they are also subsidiaries of the city – you have two important players who speak with one voice.*

In particular, the housing associations have to decide to what extent they are prepared to impose burdens on their tenants and possibly also whether to take on extra communications work or, alternatively, to bear the costs of implementation themselves.

Especially when it comes to the generation and supply of renewable energy, but also to the question of the appropriate level of energy efficiency in buildings, the housing industry is an indispensable partner, but often quite a reluctant one. This is particularly evident in projects where the building stock plays an essential role. Since there are few regulatory requirements regarding energy efficiency standards for the existing building stock, the housing associations are free to make their own decisions. Their interest in investing in the energy efficiency of their own building stock is largely determined by the landlord/tenant dilemma. If housing associations cannot pass the costs of efficiency measures on to their tenants and the tenants are not willing to pay, the housing companies themselves have no incentive to invest in efficiency measures, because they will only increase their investment costs, while the positive effects in the form of energy savings will exclusively benefit the tenants (Melvin 2018). For housing associations, this means that either they have to be able to pass costs to tenants or there should be funding from the government, e.g. in the form of subsidies.

> *At the end of the day, put simply, it is a closed system. It is true that housing associations have to look at becoming more efficient. On the other hand, the cost will always remain with the final consumer. Even the obligation to pay a CO_2 price must be generated by the housing industry from its income. In the end, it is either subsidised or borne by the final consumer. There is no other way.*

Nevertheless, housing associations do have room for manoeuvre. Examples of this are housing associations that set up their own energy subsidiaries or even operate their own heating networks. Others install their own power grids on their premises, only to operate their own 'customer system' when it is worthwhile. From the coordinators' point of view, a housing association's willingness to take unfamiliar paths depends on the one hand on whether it has the necessary resources and knowledge to apply for funding. On the other hand, the association's experience with the relevant building standards and renovation measures, and above all, the attitude of the key decision-makers such as the managing directors, seem to play a major role:

> *If you take the housing industry, there too it depends on the people involved. I don't think that our housing association has exploited the full potential of the project. On the one hand, I can see that looking at the funds they have used, but on the other hand, it is also evident in the way they have contributed. So there is clearly still potential there. I also have to say that it really depends on the people involved and how forward-looking the organisations are. And yes, what their own goals are.*

However, a lack of willingness to invest may also be related to a certain mentality, a lack of long-term perspective and limited subjective rationality.

> *We have now had the experience that, even when things like the CO_2 levy are already fixed and do directly develop a price pressure, the head of our housing association then still says in the end. 'Well, nothing is fixed yet. I'll talk to our housing industry associations first, it'll take another year or so'. (. . .) This mentality, this sitting out, is something we have unfortunately had to observe a few times with one decision-maker or another.*

Overall, under the given conditions, it therefore often seems more attractive for housing associations to rely on a supply of renewable energy than to strive for higher efficiency standards in order to save energy. Therefore, one coordinator also sees the housing association in their project as the clear 'winner' of the proposal, as it does not have to make any investments itself in order to benefit from a better primary energy factor. However, this also makes certain energy plans that rely on a low heat demand in order to supply the buildings more difficult to implement. In new buildings, on the other hand, efficiency standards are now so high that the integration of renewable solutions is much easier. In addition, for new buildings, specifications for necessary measures can be defined to a greater extent through development plans or purchase agreements, although the decision lies with other actors such as the municipality.

Overall, this shows the contradiction between the goals of achieving climate neutrality and avoiding social burdens. With reference to both the affordability of housing and the cost burden on tenants, as well as their lack of interest in sustainability, it is therefore easier to reject stricter specifications and requirements for higher efficiency standards than to expect residents to pay higher, but sustainable, energy prices.

4.4 Energy Suppliers and Plant Operators

The situation with energy suppliers is somewhat different, but no less difficult. In the case of most lighthouse projects, the municipal utility companies are involved. Every solution – usually a district heating network coupled with various suppliers (waste heat from industry or from electrolysis, heat pumps, a connection to the wider district heating network etc.) – also requires a company that is responsible for operating the supply systems, as well as for marketing and selling the energy. Municipal utility companies bring both the appropriate resources and the necessary experience to take on this task and are therefore the natural choice of partner.

> *If you want to realise a climate-neutral district, then first of all, it's a question of energy supply, and then of course you talk to the municipal utility companies. It's about electricity and heat. They, or a subsidiary of theirs, will also have data. So it was quite natural that the supply should actually come from the public utility company, especially since they are also a subsidiary of the city. The fact that a lot of things were done without them is simply because in many respects they were not cooperative or the economic side was not attractive enough for them.*

However, this natural choice of partners often does not go very far. While for the researchers and, in some cases, also the municipal partners, a sustainable energy supply is the primary goal of the projects, this looks different for the power supply companies. Not surprisingly, their priority, as with the housing associations and other practical partners, is above all the economic efficiency of the solutions to be implemented. Other goals, such as the avoidance of emissions and the alignment of the supply systems with the climate goals of the German government, have to be subordinated to this goal. However, what also surprises the coordinators over the course of the projects, and is clearly expressed in the interviews, is how narrowly economic efficiency is often understood in this context and by which factors it is influenced.

> *'Not economic' means below the expected return of a gas plant.*

Accordingly, economic efficiency usually means economic efficiency *at the present time and under the present conditions*, whereby existing and conventional solutions are always used as the reference. The lack of a long-term perspective and a strong orientation towards the status quo are striking. In addition, opportunity costs are usually not considered. From the coordinators' point of view, power supply companies do not sufficiently take into account possible price increases that would make a fossil fuel plant more expensive in the future and therefore would justify investment in a renewable solution. Conversely, they are quick to assume that the new plants, due to a lack of experience, will lead to high costs, e.g. for personnel, which will in turn negatively affect the economic viability of the plans under consideration.

While some energy supply companies take decisive steps towards the transition to a renewable energy supply, many still seem to be inclined to see the problems rather than the opportunities. This industry sector is therefore often seen as rather innovation-shy. While some interviewees maintained that being in the black would be a good result for the new district energy plans under prevailing conditions, some companies are still aiming for profit margins that make the implementation of climate-neutral concepts under these current conditions difficult. However, with regard to economic efficiency, one interviewee also points out that in the end it is less the specific calculations than the personal views of the decision-makers, their foresight and willingness to take risks, as well as their trust in the statements of the project partners, that make the decisive difference.

> *And as I said, money is of course important, but I don't think it's really just a question of how many cents something costs or how much additional cost there is in percentage terms, but whether the actors are convinced that this is necessary in the future and whether they are willing to take risks. And every new solution has risks, of course, because it is simply unknown.*

Getting involved with proposed solutions where the economic viability of an operation has yet to be proven is apparently also an option if managing directors expect to build up competencies and gain experience. This view is also supported by the fact that in some projects a change of operator or the willingness of various actors to establish a new company eventually ensured the implementation of innovative concepts, albeit partly at the expense of the original goals and with certain limitations in terms of emission savings.

As was the case with the housing associations, power supply companies faced difficulties in supporting implementation under the business and regulatory conditions that prevailed at the beginning of the project. Therefore, some lighthouse projects applied for an extension in order to be able to ensure even partial implementation. One important reason for this seems to be that the factors governing whether a plan is economically viable have changed considerably in the meantime, particularly with sharply rising prices for fossil fuels in 2021 and after the Russian invasion of Ukraine in 2022. Finally, the duration and intensity of the joint work obviously pay off if the projects can contribute to learning effects and a change in values.

4.5 Coordinators, Project Developers and Development Agencies

At the centre of all projects stands the coordinator: he or she keeps an eye on the different issues, mediates between the partners' different interests and drives the project forward. It is the coordinators who ultimately have the task of bringing together all the different interests, expectations and competences and using them to develop a proposal. In almost all the interviews, the conclusion was that project management was much more important than had been assumed at the beginning and that more resources were needed for communication and coordination at the beginning than usually estimated for research projects.

However, since the expansion of the energy plan and the operation of the plants are to continue beyond the project period, this coordinating role also needs to be guaranteed in the longer term. In the view of some interviewees, however, some cities could be overburdened by this role, as a city's main influence on a district usually ends with the conclusion of the development plan and therefore many cities lack the corresponding resources to continue guiding district development. Therefore, project developers or development companies have an important role. Due to their experience with such projects and the necessary competences in the area of planning and approval procedures, as well as the acquisition of funding, they seem to be more able to push the projects forward and, in the best case scenario, ensure sustainable district development beyond the project period. However, there can be negative effects if this role is not occupied or the corresponding commitment is lacking, as one interviewee reported:

> *In addition, there needs to be a timetable and development plan (. . .) for the district. Here, the development company is responsible for coordination. It has coordinated the soil remediation and is taking care of road planning, development planning, and so on. But now, there are some open questions. At the moment there is no timetable (. . .). And obviously the project developer is either not able or not willing to (. . .) make a schedule and plan, which street building plots etc. can be built on in the next five years, and when and how this can happen. And of course this causes difficulties for all actors who now have to make a plan, because they don't know what they will be able to make happen. (. . .) There is a deficit here.*

At the time the interviews were conducted, i.e. in the fifth year of the projects, most consortia found that it was still an open question as to how the development of a district could be continued in accordance with the intended goals after the end of the project and how the continued operation of individual solutions could be ensured.

4.6 Citizens

In addition to the actors who are directly involved or at least associated with the projects, there are also actors who are not part of the consortia, but who should nevertheless be involved. These include in particular the wider public, the citizenry and the current or future residents of the district. These people are involved in the lighthouse projects through either the city or other project partners, such as social science institutes. A key challenge here is the question of the right form of participation, as well as how to deal with the imponderables of the planning process.

> *So of course we have the citizens, with whom we have been in contact from the very beginning. We have always involved them from a very early stage. We did all kinds of things, including an information container and events. They don't understand the timeline and, of course, they don't understand the funding issue at all. They hear about a large sum of money and then want to see something happening for that money. The excavator should start rolling right away. Yes, it's the excavator that counts, nothing else counts, no development plan or anything. It has to be visible, which makes the whole thing extremely difficult.*

Likewise, in the case of internal communication, the participation of the broader public and the demand to be as transparent as possible in planning create further difficulties when it comes to building trust among project partners and their ability to develop and discuss solutions together without putting pressure on the partners from practice by prematurely going public with plans.

> *And then there is this factor of uncertainty. Maybe we were very cautious or too cautious in many places, so that we simply didn't communicate things we weren't sure about. But we have seen for ourselves how often the project was already dead and then took another turn. You really can't communicate so openly in the process, because you always step on the toes of a stakeholder in the end. And that makes it difficult.*

One challenge in many projects was that many of the new districts were to be built from the ground up and thus no residents were there to discuss the plans with. Therefore, alternative methods of participation had to be found, e.g. by communicating with other residents living close by. However, what the project partners planning the participation see as particularly difficult is a lack of interest and understanding on the part of the residents – especially over a longer period of time – when it comes to participating in the developments. The right form of participation and involvement, as well as public relations work, is therefore an ongoing challenge for all projects.

4.7 Funding Agencies, Project Executing Agencies

Finally, among the external actors, the ministries and the project executing agency (as the funding body) naturally play a prominent role. As the considerations regarding the typical course of projects above have shown, the funding agency must be prepared to go along with the recursive loops and the resulting delays and to allow the partners a high degree of flexibility in the face of the imponderables that arise. It was repeatedly emphasised by the interviewees that the organisation in question has fulfilled this role to an extraordinary degree. This especially applies in circumstances when partners have dropped out or the concepts had to be largely rescheduled due to unforeseen events.

> *I can say with certainty that there was never a lack of goodwill on the part of the project executing agency. We looked for solutions together and they were always very sympathetic in examining the proposed solutions or making suggestions.*

The willingness to keep looking for creative solutions with the coordinators was rated extremely positively by all interviewees. However, as will be discussed below, certain hurdles resulting from the funding regulations could not be removed and these sometimes represented major barriers to successful implementation.

> *Of course, we experienced this cooperation as very constructive and solutions-oriented on the part of the project executing agency, particularly the way that this support and supervision takes place. We feel that we are really being supported in order to make solutions possible. Nevertheless, there is a clear definition of the framework.*

4.8 Interim Conclusion

Overall, it can be said that different actors are pursuing very different interests. Especially with regard to their goals, they have very different expectations of the projects and bring different competences to the table. These differences must be absorbed and channelled through skilful coordination and the management of the logistics of the projects. What conclusions the coordinators therefore draw for project management is discussed in more detail in the last section.

For all actors, however, it is not only the institutional environment that plays a prominent role, but above all the specific individuals, their views, their relationships and their willingness to cooperate.

Trust is the decisive currency here. It is no coincidence that project consortia often consist of groups of actors who have worked together successfully on projects before or that they only come into being because of a pre-existing network between crucial actors. However, in each project there can be a change of personnel and without certain actors the success of the project can be endangered. Often, therefore, trust has to be built first and it is this trust-building work that plays a decisive role in the projects, consuming a lot of time and resources for communication.

Trust is also particularly important when it comes to taking risks and going down unusual paths, which is a basic requirement for projects that are seeking innovative solutions. A lot of information and data is not readily verifiable. It requires trust in the researchers that their calculations are correct, which is more easily achieved if there is an understanding of what they do. Both can often only be acquired in the course of the projects. Conversely, on the part of the researchers, there must be an understanding of the needs and perceived scope for action of the practitioners in order to be able to work constructively with each other at all.

> *Why does it work or not work? Of course, this depends a lot on the willingness of the individual actors. And I think that there are very different actors. Many of the difficulties we have had, and still have, are related to the fact that individual actors, consciously or unconsciously, have – might I say? – simply pushed back many innovations. Or they have not supported them, or have only constantly mentioned the counter-arguments, or withheld information, or used killer arguments. And, of course, networks are also used to prevent changes and the like. So it is all these things that play a role and that often are only assessed under the conclusion that change brings about insecurity. (. . .) When people like that are in unfavourable positions or in important positions, then of course the question of credibility is a problem.*

5 External Factors

However, it is not only the actors, their goals, their competences and their behaviour that have a significant influence on the course of the projects, but also a number of different external conditions. Among many relevant factors, we can identify three key ones from the interviews. In addition to the regulatory environment, the existing structures, as well as the debates and events surrounding climate change itself, seem to have a big impact on the living labs.

5.1 Regulatory and Funding Environment

"Regulation is one of the biggest obstacles, not only with the laws as they are, but also with the element of uncertainty that they bring to a project."

Regulatory issues and, as part of this, funding conditions are among the most frequently mentioned factors on which, although they can hardly be influenced, a project's chances of success depend significantly. Every project also has to deal with lots of legal issues that, even if these can often be resolved, tie up many resources and take up a considerable amount of time along the way, starting with questions of data protection and how to obtain certain information, e.g. from the population register, and leading all the way to approval processes.

> *I mean, data collection in our district was not a trivial matter either, of course, with so many players, and then you have the issue of the General Data Protection Regulation. It takes a lot of effort to get energy consumption data, but also to find out things like how many people live there. Registration data are among the worst. Of course, this data is held by the city, but even there it is not shared internally.*

The legal issues are further complicated by the fact that the lighthouse projects are meant to be innovative. This means in particular that there is often little to no experience with the solutions envisaged. It is therefore very difficult for there to be complete legal certainty, which is why certain risks have to be taken if implementation is to be successful.

> *If the regional council had said: 'You need a safety zone', then that would have been it for the project. It was tense, because the approval process is a lot of work. And we were lucky that there were people in the regional council who were willing to go along with it and were a bit experimental. There was no blueprint. If someone is sitting there who is a little less courageous, then that may be it. Because if something goes wrong, someone takes the responsibility. And in cases where there's doubt, it's those who approved it.*

One example that appears in various projects and combines many of these problems is the establishment of customer systems – a concept that seeks to connect consumers and producers within a defined area in their own electricity grid, whereby one can generate and sell the electricity produced in the district cheaply and exempt from various fees. The realisation of a customer system is therefore sometimes decisive for business models and their economic viability. However, many legal questions have to be clarified and even then, a residual risk often remains:

> *Unfortunately, you don't apply for this status anywhere. You can just take it, but then you're vulnerable, that's the problem, until someone sues. That's why you have to have legal certainty. Well, in any case, we have obtained legal certainty with an expert opinion.*

The legal environment in particular often determines a project's economic viability. In one project, for example, the combination of a customer system with the concept of mini-photovoltaic systems, which the residents could hang on their balconies to become prosumers, would not have been economically viable due to the requirement for medium-voltage meters associated with the customer system. These and other hurdles then led to a decision not to introduce the customer system. In other cases, such hurdles could be removed through the intervention of other actors, e.g. by stipulating construction requirements or even a connection and use obligation in development plans and purchase contracts. However, this also required impositions, for example on the part of investors and residents, and was therefore accompanied by a great deal of persuasion and discussions about legal issues. An even greater effort was made in those projects where there were plans to found a new operating company.

However, some hurdles cannot be overcome even with the most risk-tolerant actors because the legal framework completely undermines economic viability.

> *Technically it's possible, but you can't make it economically viable. Switched-off wind power, if it is no longer switched off, with all the levies and charges, is no longer green as soon as it is in the grid. Even if you say it comes from the wind turbine, it is still only one-third green, because then the federal mix counts.*

Even though there may be good reasons for many regulations, they still can make things very difficult for actors who are looking for innovative possibilities for local energy supply and trying to find economically viable alternatives to existing technologies. It is therefore not enough to develop technical solutions; very often, a host of difficult legal questions must be clarified along the way.

An essential approach to compensate for a lack of economic efficiency is to provide the actors with sufficient funding for implementation as well. As far as the legal funding framework is concerned, however, the coordinators' assessment is equally ambivalent. For even if the basic material equipment of the projects is assessed as positive, the necessary conditions for investors essential for implementation are not attractive enough to sufficiently lower typical barriers to innovation. Respondents see the main cause of this as related to EU state aid regulations (EU 2014, in particular Articles 25, 36 and 38). According to the funding regulations for the lighthouse projects, only 50% of the depreciation of investments during the timeline of the project is subsidised. This means that for technologies and infrastructures with long life spans (for example, of 25 years), only 50% of the depreciation over the project period – i.e. a maximum of 5 years – was financially supported, reducing the funding in this hypothetical example to 10% of investments. Therefore, it remains unattractive for investors to invest in systems and facilities with long amortization periods, such as district heating networks or energy control centres.

> *When investments are funded in research projects, only depreciation is funded. Of course, this has to do with the EU's state aid framework. However, the state aid framework also allows for other approaches, if one were to take them into consideration. But then one would not be allowed to promote according to Article 25, but would have to take Article 36 or 38 as a basis. As a rule, however, these were not included in the research funding guidelines.*

In the application phase, the business partners from the field usually did not yet have a detailed awareness of the funding conditions, either because they did not yet have an eye for them or because the consequences of these regulations for project investments might have been difficult to assess beforehand. The EU regulation, for example, was relatively new and only was implemented in the year 2014, just three years before the projects actually started and therefore it is possible that not all the partners knew about it or completely understood its implications. The crux of the matter, identified in all projects, is that the funding conditions for research are good, but those for implementation were not seen as equally as good – and yet implementation, according to all interviewees, is at the core of the living labs and the lighthouse projects. Therefore, implementation faces major hurdles even with funding. For successful implementation, the partners are not only dependent on other funding sources, such as Germany's Kreditanstalt für Wiederaufbau (KfW), they must also be familiar with the corresponding regulatory framework and administrative procedures. Consequentially, the project consortia often had to reduce their goals of climate neutrality from their original aims, which was, among other reasons, often a combination of insufficient compensation from funding or other sources and risk aversion.

5.2 Existing Structures, Energy Prices and the Question of What a Sustainable and Decentralised Energy Supply May Cost

Another significant aspect in all projects is the competitiveness of innovative energy concepts relative to established supply infrastructures. Innovative technologies are at a disadvantage compared to established systems in many respects, which is also evident in the projects. Just as the legal framework is not yet adapted to the new systems, the wider environment and existing infrastructures are not yet aligned with the innovative concepts. Among other things, this is in some instances discussed as a chicken-and-egg problem when it comes to the question of whether one first has to establish supply structures or whether there first needs to be sufficient demand. A good example is the production of green hydrogen. Although from at least one coordinator's point of view there is a broad consensus among experts that this is an indispensable component of the energy transition, even though not necessarily within residential areas, the demand in general is often still lacking. Furthermore, there are not only questions of economic efficiency, but also questions about connection to existing infrastructures.

> *And there are certain conditions that we set. In the regional context, I really need demand for hydrogen, or at least the prospect that this local demand will emerge in the future. Only then does it make sense. Because otherwise I have to think about how I'm going to transport the hydrogen over long distances. And then it's not justified. I also have to make sure that the hydrogen plant has a heat sink, either a district heating network or connected buildings. And there are restrictions here, too, because the consumers must also be able to use a corresponding temperature level.*

Special attention must be paid to the coupling with existing structures in existing districts, as here the entire district cannot be planned anew, but the existing structures must be worked with. The matter is further complicated if existing facilities have not yet been fully depreciated and amortized. Since the funding is usually not sufficient to compensate industry partners sufficiently for the existing hurdles, it is necessary to look for other synergies to overcome the concerns:

> *In addition to the residential buildings that are included in the district, we also have a school that is included. A primary school that is owned by the municipality, which is due for energy refurbishment anyway, and this was a good opportunity to find synergies there.*

However, the main problem in all the lighthouse projects, which concerns both new construction and existing buildings, is that from the viewpoint of the intended operators, the innovative systems do not always fit their business model and it is often difficult to operate them economically. On the one hand, certain approaches, such as the idea of saving as much energy as possible through efficiency measures, contradict the business models of the power supply companies, who earn their money and recoup their investments by selling energy.

> *A major conflict where we tried to bring the actors together was that the more energy I save to become green – for example, by using building systems technology to increase efficiency – the more difficult it is, of course, to recoup the costs of the entire system. Because in the end, I have to recover the same costs with less energy consumed, which therefore has to be more expensive.*

On the other hand, due to their lack of experience in dealing with the innovative systems, operators anticipate risks that are then reflected in the costs, while they usually do not take into account the opportunity risks of existing systems, such as rising fossil fuel energy prices.

> *But the risk factor for the established system is never considered anywhere. For me, it also has a risk. That is, the risk that, for example, gas prices explode or gas no longer arrives at all. They do not take this risk into account at all, even if it is only an opportunity risk.*

These two factors contribute significantly to the view that systems based on renewables mostly cannot guarantee a price for heat that would be comparable to prices from conventional systems. The high investment costs, which cannot be entirely cancelled out by the subsidies, undermine the economic viability of renewables, because even if the energy costs through renewable energy are low in some cases, the apportionment of the necessary investment costs increases heating costs considerably. Due to the competition with existing systems, which are assessed to be cheaper in this respect, and due to both tenants' and housing associations' lack of willingness to pay for green energy, the operators make it in basically every project a condition for their participation and investment that the implementation is quasi neutral with respect to rent, including heating costs.

Even with stipulations of compulsory connection and use of the district heating networks, nevertheless, neutrality of rent (including heating) was in several cases declared a condition for implementation. A major problem here is that the current prices for fossil fuel energies are usually taken as a reference, which have changed only very moderately since 2017 and for most of the project term. It was only towards the end of the project term, from 2021 onwards, that the prices of fossil fuel energy began to rise sharply, partly due to the CO_2 price, but much more significantly due to the global economy picking up after the COVID-19 pandemic.[3] The fact that the additional costs are always compared to costs that prevail at the present time is therefore tantamount to a lack of a long-term orientation on the part of the actors.

3 In the meantime, Russia's war against Ukraine and the associated sanctions have been added as a further factor. However, this development was not yet foreseeable at the time of the interviews and therefore did not play a role in the project evaluation at that time.

It is true that the question of additional costs is a very variable story, in that one must of course estimate the associated reference costs and the fossil fuel costs. Look at the development of gas prices and heating prices now. Under today's boundary conditions a profitability calculation is very different from what it was two years ago.

The expectation in the projects was therefore that the government funding would completely close the gap between the economic viability of a fossil fuel and a sustainable energy supply, but this proved to be unrealistic. In the search for a compromise, therefore, most consortia ultimately considered solutions that moved away from the goal of climate neutrality instead of abandoning the idea of keeping energy prices the same.

The [housing associations] are very tough, according to the motto 'What's the price? We'll take another look at that. We aren't going to connect our buildings if it is more expensive than district heating or something like that.'

The comparison with existing systems also makes the evaluation of the innovative solutions difficult. The sharp rise in energy prices since 2021 certainly played into the hands of the partners to some extent, especially since the players have become aware that there is no simple 'business as usual'. However, at the same time, other costs, such as construction costs, have also continued to rise sharply, so that even with the sharp increase in gas prices (before the war in Ukraine), fossil-fuel-based solutions were considered more attractive by many energy suppliers. An almost grotesque effect of the increases in oil and gas prices was the impairment of utility companies' ability to invest, because they were not able to pass the prices on to their customers at the same rate. This has reached such extremes that in one project a partner originally intended to be the operator of the energy systems actually had to file for insolvency.

There are two stories here. On the one hand, the increase in gas prices means that renewable energy solutions are suddenly becoming more competitive. And it is also the case that the power supply companies and customers naturally see that alternatives must also be developed. That's positive, but it's also true that the power supply companies are now under much more economic pressure and, even if they wanted to – as a result of these initial effects, they can no longer do what they want.

All this shows that little attention is paid to future price developments. Instead, the strong adherence to the status quo makes it very difficult for projects that are trying to bring about a long-term transformation to keep their promises. And this also raises another question that is lurking under the surface of all the interviews, namely the question of what a sustainable and decentralised energy supply may actually cost and who should bear these costs. Because, in the end, it is either the state or the end consumer who has to pay the costs for this sustainability transformation, and as long as neither party is willing to do so and new business models hold too much risk and provide too few gains, the players' hands remain tied from a business point of view.

> *But the managing director's hands are also a bit tied. And he also emphasised yesterday that people are now desperate to buy gas connections everywhere. And this makes him happy economically, but actually it is not the right signal. In this way, he also made it clear that he theoretically has a different mindset. But if the shareholders make a different decision, then they make a different decision. Then he has to take it and implement it.*

5.3 Climate Change and What Sustainability May Cost

This also brings us to the question of what role the climate discourse and the environmental awareness of citizens play in the projects. As a factor that affects the projects, all actors assess the increasing debate around climate change as very positive. The debate changes the attitudes of individual actors, and leads to a changed dynamic in which, for example, city councils adopt 'climate action master plans', 'integrated climate action plans' and 'climate action targets'. Additionally, new regulatory instruments are being introduced, such as the CO_2 price. However, there is another side to this, of which the CO_2 price is also a good example. While the trend is going in the right direction, the individual steps are, in the view of the interviewees, far from sufficient to support the desired transformation of the districts, just as the level of the CO_2 price is far from sufficient to bring about significant changes.

However, in addition to citizens' insufficient interest in sustainable behaviour, they often also lack the willingness to pay for sustainability. Furthermore, for some social classes there is also a limited ability to pay for sustainable energy provision – especially for people living in social housing, which accounts for many residents in the projects in question here, due to the frequent involvement of municipal housing associations. This in turn serves as an argument for all stakeholders for not allowing prices to rise too far.

> *Many don't have the money. But many don't bother with it either, that's another thing. That means that the electricity comes out of the socket and somewhere I have a heating regulator, I turn it on and it gets warm. Thus, if someone says that you can somehow reach 60, 70, 80 percent of the population because you have a green image, you won't have that.*

Even though many project partners, especially those involved in participation and public relations, were afraid that the fear of certain technologies and the lack of acceptance among the local population would hamper the projects, these aspects proved to be not very decisive, which could, however, also be an effect of the participation efforts. However, what was a huge barrier is the fundamental lack of willingness to pay for a sustainable energy supply – this inhibits a sustainable transformation.

> *And then people say, yes, we don't want to pay. There is natural gas, which is cheap if it comes from Russia, or let's see where it will come from.*

Another ambiguous effect lies in the public perception of the projects. Generally, the visibility of the projects is rated as very high by the coordinators, which also benefits the projects' claims to be lighthouse projects and can have a motivating effect on actors such as the city, who see themselves as responsible for generating visible results from the funding. However, according to the coordinators, this visibility can also lead to negative effects among the local citizens – e.g. when citizens perceive the projects as heavily funded but not very productive, because they have problems understanding the research logic, they have difficulties staying motivated and interested over a period of five years, and in the end it is mainly the visible changes that are perceived. Particularly in the case of less visible successes, such as the design of a development plan or the conversion of hidden infrastructure, it is not to be expected that there will be storms of enthusiasm and therefore also no increased willingness to pay.

6 Transfer and Lessons Learned

To what extent do the lighthouse projects live up to their name and have an impact beyond the district? How does the transfer of knowledge take place? Moreover, what concrete lessons can the coordinators draw from the projects?

6.1 Knowledge Transfer

On the purely technical level of developing a plan for a sustainable and local energy supply, it becomes apparent that, depending on the local conditions, a few elements must be combined in order to generate added value in the sense of an energy supply that is as cheap as possible, accepted by residents and adapted to its context. This includes, firstly, the fullest possible usage of local energy sources, such as through the solarisation of roofs or even façades in order to generate enough green electricity within the district, but also through the use of geothermal or waste heat energy, depending on the local context and the availability of different energy sources. Secondly, buildings have to have certain efficiency standards to ensure a sustainable heat supply. The higher the efficiency standards of the buildings, the lower the heat demand that needs to be met and the easier it is to apply low-temperature systems such as heat pumps or low-temperature district heating. Thirdly, synergies must be exploited by coupling the different sectors, such as electricity, heat generation and transport, e.g. by supplying district heating networks via heat pumps, powering combined heat and power plants with biogas or using waste heat from industry or electrolysers. The presence of heat sinks that can cope with lower supply temperature and the supply of renewable electricity, as well as the possible economies of scale and the location of a project – e.g. in the middle of an urban area vs. on its outskirts – then determines whether individual modules such as electrolysers are profitable within a certain setting. Fourth, the possibility of storing energy surpluses from fluctuating renewable energy generation and the integration of the district network into the wider grid, in order to balance differences in the supply and demand of renewable electricity between regions, are needed.

These various elements are always necessary in one form or another to supply districts with sustainable energy, but the specific system modules have to be flexibly coupled depending on local conditions. Depending on these conditions, one then has to choose whether to use, for example, geothermal energy, industrial waste heat, solar or wind energy for supplying electricity, heat and electric vehicles.

> *Everything else is scalable in principle. Depending on the orientation of these buildings, you could then integrate more or less solar heating or PV. Geothermal energy is a big topic in various areas. But if you go to the sea or to somewhere with open space, you might have instead a wind turbine. Or you could consider using industrial waste heat. Thus, this basic system is so scalable that it can really react to most circumstances.*

In addition to the structural-technical background, a number of other factors (discussed in detail in Section 5) are essential for the success of the project, especially with regard to legal issues, financing questions and questions of acceptance. However, the projects also show very clearly that one of the biggest hurdles that sustainable district solutions need to overcome is that they are currently not economically feasible – the necessary requirements are simply not met. As long as none of the actors is willing or obliged to accept higher heating prices than they have been used to in the short term, these plans will have a hard time competing with gas and oil.

Even if the general conditions – after the interviews were conducted – have changed considerably as a result of the war in Ukraine and are likely to contribute to a further rethink, the development of heating infrastructure in Germany clearly shows that there is still a long way to go before climate-neutral supply will be achieved. In 2020, the share of energy sources for the heating structure in the German housing stock was still 49.5% gas, 25% heating oil and 14.1% district heating (BDEW 2022), with 75% of district heating being supplied by fossil fuels (dena, 2022, p. 47). Less than 10% of the energy for heating comes from renewable sources. Moreover, it is way too early to interpret the efforts to become independent from Russian gas as a more fundamental shift away from fossil fuel energy sources. Rather, it is likely that in the medium term, policy-makers will focus more on a return to former price levels than on a forced conversion to sustainable structures.

In view of these hurdles, it is quite uncertain whether all the projects will see the implementation of the envisaged concepts by the end of the project terms, even with the extensions. What seems certain, however, is that large parts of the plans could not be implemented as envisaged at the beginning of the projects, whereby adjustments were often made at the expense of climate neutrality.

Nevertheless, all the coordinators rate the projects as on balance successful, even if there were disappointments, and they mention a number of results that contribute to this success and a successful knowledge transfer. Overall, one should not forget that, from the coordinators' point of view, the projects are living labs, and a crucial aspect of living labs is to show what is possible under the existing conditions if only one is given resources and time to look intensively at different options.

> *For me, a living lab project is successful when I deal with the real problems that are there within the project, understand them and help to solve them or develop them further and learn something from them. And here, like all the projects probably did, we have had many experiences that made it much more difficult than expected.*

Four dimensions can be extracted from the interviews that constitute a successful knowledge transfer.

1) At the level of the districts in the six lighthouse projects, it is the decisions that particularly paved the way for further district development, such as concrete guidelines. This includes, for example, the adoption of guiding principles in the municipal council, the co-design of development plans or the definition and specification of criteria in purchase contracts.

   > *On the plus side, we have a good development plan, which has become better through our work. We have a mission statement, we have a requirement to install solar panels, we have low-temperature heat. We have set a course that is definitely there. From that point of view, there are things that are really visible.*

2) The lighthouse projects provide learning effects; because the actors involved accumulate knowledge, refine their solutions and adjust them to consumers' needs, this knowledge then becomes the basis for every future project. Some actors, however, also experience a change in attitude. Awareness of sustainable development is heightened and old certainties are questioned.

   > *All these soft factors, knowledge gain etc., they definitely also came about for all the partners in the project. We also had a few partners, from pump manufacturers to developers of information technology solutions. Of course, they all benefited greatly. Simply because the systems are much more sophisticated or more oriented to actual needs.*

3) The participating stakeholders pursue the concepts developed in the lighthouse projects in subsequent projects, in which they further refine and develop the solutions and where they can refer to and even demonstrate the results. Therefore, the lighthouse projects act as catalysts for the partners to get new projects, for example, because they can show concretely what they have achieved and let other actors share their experiences, including pointing out which mistakes should not be repeated.

   > *We are already preparing this in other projects. In one project, for example, they are building a new district for sixteen thousand inhabitants. Since we've now tested our system on a small scale, we're rethinking it so we can repeat it on a much larger scale in the new project.*

4) Lastly, successful knowledge transfer means that projects test the limits of what one can achieve under current legal, regulatory and financial conditions using current technology – they should also show what is not possible and where the concepts fail. The living lab projects show how laborious coordination processes can be and how important it is to deal with processes and structures. Learning from this experience and presenting these experiences is crucial, which is why we have publications like the current one.

> *We also learned what barriers and obstacles there are: What are the real problems? What are the fears? What are the legal or financial hurdles? What are the lines of argumentation? And afterwards it is also important that it's not just me personally or a handful of others who have learned this, but that it is also more widely analysed and communicated.*

These various points also clearly reflect the importance of living labs as research projects (as opposed to pure implementation projects). Living labs provide resources and time to pursue ideas that otherwise would not have been pursued and to make things happen that otherwise would not have happened, even if these things were often not planned from the beginning. And during the process, actors have also had to take on different loops and deal with many insecurities. Thus, the goal for many actors is to reach the point where research funding is no longer needed, because the pitfalls are then sufficiently known, but where funding for projects is only required to sufficiently compensate for the lack of profitability of sustainable systems compared to existing ones.

6.2 Findings for the Implementation of Research Projects

In addition to these four dimensions, there is also another class of experience, namely that which relates to the organisation of such transformation processes and even more narrowly to the organisation of living lab projects.

> *One should clearly separate these classes of experiences in this presentation. One experience is in terms of implementation, technical solutions and processes. The other one is: How do you organise something like that? Or what are the obstacles, so to speak, in terms of process and organisation? Perhaps you could even add a third level: What does this actually mean for the organisers of living lab projects? On the one hand, we want to disseminate findings that work in a project development without a funding framework. But what we have just discussed rather relates to: What experience do I have in a funded framework?*

Especially on this procedural level, the coordinators cite many insights regarding what they believe coordinators in similar projects should pay attention to in the future. Even though some of the following aspects are difficult to influence, they still serve as warning signs and can be essential starting points to avoid unnecessary feedback loops and delays.

The interviewees raised the following points in particular:

1) An intensive and trust-building cooperation between the different actors within a project is crucial for the success of research projects: partners on the ground should be heavily involved as early as possible in the development of the concept, but without losing sight of the fundamental objective of sustainability and without unnecessarily narrowing the search for new solutions. For it is precisely by pursuing supposedly unattractive paths that new possibilities arise and ultimately lead to surprising results. However, it is essential to actively involve the addressees in the process and thus create trust, understanding of the process and solutions that meet actual needs.

2) To build this trust, communication is key: many coordinators seemed surprised at how much communication was ultimately required. They therefore recommended making sure from the very beginning that the partners regularly communicated their results to each other in an addressee-appropriate and descriptive manner, in order to avoid individual research partners silently working on their own. On the other hand, close bilateral exchange could not be overrated, because within large groups individual partners could easily withdraw from responsibility and progress is usually made in smaller settings.

3) In order to build better bridges between research and practice, a dual leadership with one research project leader and one representative from the practice side, often the municipality, would be beneficial for project administration; this would make it easier to mediate between the different styles of thinking and acting, for example between public administration, research and companies.

4) Coordinators must always be aware that the progress of a project ultimately depends on specific people. A lack of trust or the existence of hidden agendas, especially among people who sit at crucial interfaces, could severely disrupt any project, no matter how ambitious. Trust is therefore the key factor. However, even though there are many possible ways to establish and promote trust, there is no guarantee of a trusting cooperation. From the point of view of almost everyone involved, it is therefore a great advantage if there are caretakers or decision-makers in the projects, well-connected mediators who support the project's objectives but also have the power to resolve deadlocked situations. These are the kind of people who, if they are not sufficiently involved from the beginning, coordinators should try to engage in the course of the projects.

5) Coordinators should also deal with the necessary external conditions as early as possible. On the one hand, this concerns questions about the space needed for installations, but also for public relations work, which needs to be organised at an early stage. It also concerns questions about who will ultimately operate the energy supply systems or whether there are possible anchor customers who already cover a large part of the demand and could thus facilitate implementation. Because the search for a suitable oper-

ating company has proven particularly difficult in basically all of the six projects, the experience of the lighthouse projects also shows that being prepared means that the consortia should consider looking for ways to set up their own operating companies early on. Alternatively, another idea would be to regularly inform a number of potential operators about the plans and thus establish a wider circle of interested but competitive parties. And when looking for anchor customers, one should also broaden one's view beyond the district boundaries, as actors in neighbouring commercial areas or other city districts can also make the decisive difference.

6) The legal framework is considered one of the main factors influencing the various projects. Due to the abundance of legal topics on which sustainable and innovative energy plans often depend, several interviewees therefore rate it as very helpful to be able to fall back on local legal expertise for certain aspects. Legal advice, be it with the involvement of a designated partner or through subcontracting, could therefore be beneficial in the development of the energy plan.

7) In general, it is of great advantage if the partners know important nodes of decisions in advance and can also think about strategies for how they could influence them. This applies in particular to districts where the development is starting from scratch and where it is possible to incorporate specifications into development plans and purchase contracts, and thus set the course for sustainable development early on. In a slightly different way, it is also important for redevelopments of existing districts, e.g. when resolutions of the municipal council have to be sought in order to be able to refer an issue to the political decision-making level in the case of difficult decisions. Project goals such as climate neutrality should be defined in sufficiently concrete terms as a basis for decision-making and delineated from other goals so that they are not too easily softened in retrospect.

Beyond these seven lessons learned, a final point to be considered – although it can hardly be influenced by the coordinators themselves – concerns the project duration: in almost all the lighthouse projects, there were plans for a cost-neutral extension of up to two years. Even though concept development should usually not take much more than three years from some coordinators' point of view, it is the coupling with implementation and the resulting feedback loops that lead to delays and make implementation – not to mention a monitoring and evaluation phase – within five years so difficult. However, the projects also show that it is only the prospects for funding for implementation, and the persistent attempts to get into implementation, that lead to repeated refinements of scientific concepts and that make implementation possible at all. It therefore seems crucial to have a prospect for the funding of the implementation from the very beginning of a project. However, in the eyes of some coordinators, it could also make sense to have some interim evaluation, after which the consortia should then more easily be able to apply for extended time and resources for implementation and even an additional evaluation phase.

For the implementation – and this has also been clearly shown by the projects – improved conditions for supporting practice partners are also needed; funding of long-lasting infrastructures is definitely not sufficient under the current conditions (see Section 5) to really motivate the practice partners to an implementation.

Although there have been some disappointments for the interviewees, especially concerning the implementation of the sustainable concepts, the overall results show how much the different partners have benefited from the projects, the different ways one can learn from such projects, and how different the results and knowledge transfer such projects can look. Even if it is impossible in the planning of research projects to ensure compliance with all the criteria that were assessed as helpful by the interviewees, these experiences can nevertheless provide important impulses. They show that one should expect and can anticipate corresponding developments and that it is better to start dealing with these issues sooner rather than later. What else can be learned for sustainable district development in terms of technical implementation and the various processes is dealt with in detail in the other contributions to this anthology.

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Contributors

Carolin Alippi, B.Sc., has been an assistant to the management of Alippi GmbH since 2017 and is a project employee in the research project ZED, in the sub-project "Micromobility in the neighbourhood". After training as a nurse at the municipal hospital in Zwickau, she studied business administration (Bachelor of Science) in Berlin with a focus on business succession.

Thomas Anton, M.Sc., Dipl.-Betriebswirt FH, has been a member of staff at the Institute for Applied Material Flow Management since 2003 and has been head of the Energy Efficiency and Renewable Energy Division since 2007. In addition to conducting collaborative research projects with national and international partner consortia, this department offers a wide range of consulting services in the context of climate protection, energy and heat transition, sector coupling and circular economy.

Felix Bader, Dr. rer. soc., Dipl. Soz., is research fellow at the BIS Berlin Institute for Social Research. He studied sociology at LMU Munich, worked as research and teaching assistant at LMU Munich and University of Mannheim. He received his doctoral degree from University of Mannheim. He is also postdoctoral researcher in the project "Environmental Inequality in Germany" at TU Kaiserslautern. His research interests include environmental sociology, so-cial inequality, economic sociology, methods of social research, especially questionnaire de-sign, experimental methods, and longitudinal analyses.

Christian Bär, Dipl.-Päd. Dipl.-Ing. (FH), studied educational science with a focus on adult and continuing education at the Freiburg University of Education and electronics at the Furtwangen University. After gaining in-depth industrial experience in sensor development and project management starting in 2001, he has been working at Fraunhofer ISE since 2018 in the social sciences on the topics of acceptance and stakeholder analyses as well as the modeling of socio-techno-economic systems using System Dynamics. Another focus of his work is the research and application of serious games as well as visualization in educational and acceptance contexts of sustainability.

Diana Berg, M.Sc. climate and environmental change is an employee of the administration of the city of Kaiserslautern. Since 2017, she has been coordinating the activities in the EnStadt:Pfaff project at the interface between the city administration and the research and corporate partners as assistant to the project manager.

Volker Binding applies his long-time experience in analysis of illiquid products and derivatives mainly in the area of banking and finance. Volker's team at Tachycon GmbH supports portfolio managers and investors in capital markets, on the other hand he has strong relationships with research projects and with the start-up scene in the sustainability sector. Before founding Tachycon, Volker was the head of modeling and analysis teams at several banks and worked as a lecturer at various institutions. Volker holds a PhD and a Master of Science in theoretical physics from the Georgia Augusta, Göttingen.

Georg Blum, M.A., has been deputy cluster manager at the Oldenburg Energy Cluster OLEC e.V., the largest cross-technology energy network in Northwest Germany, since 2019. There he is responsible for the transfer of knowledge and technology from innovation projects and working groups and, as a trained economic geographer and economist, deals with questions of regional value creation and sustainable regional development in an energy system of the future.

Mirko Bodach, Prof. Dr.-Ing., is the head of the professorship of Electrical Power Engineering / Renewable Energies at the University of Applied Sciences Zwickau. His main research includes electrical

https://doi.org/10.1515/9783110777567-206

power engineering, renewable energy systems, sector coupling, district energy concepts, smart city, electrical infrastructure for electromobility and electrical energy storage systems and components. After graduating from high school, he studied electrical engineering at Chemnitz University of Technology, specialized in electrical power engineering. Since graduating in 2000, he has been working in the field of electrical and renewable energy technology. He was a research assistant at the Faculty of Electrical Engineering and Information Technology at Chemnitz University of Technology and has been running his own engineering consultants since 2004. He completed his doctorate at Chemnitz University of Technology with the PhD thesis topic: “Energy storage in the low voltage system for the integration of decentralized, fluctuating energy sources”. Since graduating, numerous publications have been developed during industrial research and funded projects in the field of electrical power engineering.

Elisabeth Borbe, B.A., has been a project worker and neighbourhood pilot at Johanniter-Unfall-Hilfe e. V. – Regionalverband Zwickau/Vogtland in the research project ZED since 2020. From 2009 to 2012 (Bachelor of Arts) and from 2012 to 2018 (Master’s degree), she studied media communication at Chemnitz University of Technology. She then worked at the Thalheim/Erzgebirge municipal administration in the press office, public relations, culture and tourism department until 2020.

Tobias Brandt, Dr., is a senior researcher and group manager of the group Co-Simulation of Multi-Modal Energy Systems at the OFFIS research institute.

Wolfgang Braun, Dr., has many years of professional experience in design and independent evaluation of a wide variety of analysis software for structured capital market products (interest rate, credit, private equity, derivatives, real estate and renewable energy). In addition, Wolfgang leads consulting projects on financing, structuring, portfolio analysis and risk management at Tachycon. Thanks to his additional involvement in research projects together with renowned research institutions, Wolfgang succeeds in bringing together innovative solutions and investor needs. Wolfgang holds a PhD and a Master’s degree in theoretical physics from the Philipps University of Marburg and a “Master of Science in Quantitative Finance” from the Frankfurt School of Finance and Management.

Matthias Brucke is co-founder and co-owner of embeteco GmbH & Co. KG, He studied Engineering at the University of Applied Sciences in Ravensburg- Weingarten.

Christian Buchmüller, Prof. Dr., Maître en droit, is a professor of European Business Law and head of the interdisciplinary master’s programme ‘Green Energy’ at the West Coast University of Applied Sciences in Heide.

Stefan Büscher, M.Sc., is a research assistant at the Jade University of Applied Sciences in Oldenburg and is a member of the “Institute for Applied Photogrammetry and Geoinformation” and the “Institute for Database-oriented Engineering”. His thematic focus is the analysis of possibilities in visualizing geoobjects indoor and outdoor.

Walter Czarnetzki, Dr., became a researcher at the Helmut Schmidt University of Hamburg in the field of heat and mass transfer after his studies of mechanical engineering at the Technical University of Darmstadt, Walter Czarnetzki. He completed his doctorate with summa cum laude in 1997. From 1997 to 2003, Walter Czarnetzki was head of the development department of a vehicle manufacturer and head of the technical department of a laser manufacturer. Walter Czarnetzki was appointed professor for thermodynamics and energy technology at the Faculty of Mechanical Engineering at Esslingen University of Applied Sciences in 2003. Since 2003, he is head of the laboratory for heat and flow technology. Since 2005, Walter Czarnetzki is member of the Institute for Sustainable Energy Technology and Mobility at

Esslingen University of Applied Sciences. From 2006 to 2013 he was Dean of the Faculty of Mechanical Engineering and from 2013 to 2019 Vice-Rector for Research and Transfer. In many national and international projects, Walter Czarnetzki conducts research in the field of fuel cells and hydrogen technologies in stationary and mobile application. He is an expert in designing, simulating, and evaluating fuel cell systems.

Bettina Dech-Pschorn, Dipl. Geographin, is Director of the Environmental Protection Department of the City of Kaiserslautern and head of the collaborative project EnStadt:Pfaff. She coordinates the cooperation of the eight partners from science and business with the departments of the city administration. She also coordinated the creation of the 100% Climate Protection Master Plan, which aims to achieve climate neutrality for the city. EnStadt:Pfaff is a building block for the implementation of the master plan.

Martin Eckhard, Dipl.-Ing, is working since 30 years at the interface between business, science and regions. Basis are his studies in mechanical engineering, technical-economical environmental protection and mathematics. After initial activities in design engineering and toolshop management, he was active for 22 years in innovation funding in all fields of technology with partners from science and industry. By a further change into economy he was responsible for funding within the range of automation technology. Since 2016 he is developing the PtX-initiative ENTREE100 at Entwicklungsagentur Region Heide. He gives support to all regional partners in all questions concerning funding, develop new projects and coordinate QUARREE100.

Moritz Elbeshausen, B.Sc., is currently masters student at the Jade University of Applied Sciences in geoinformation science and participating in research projects of the IAPG as part time employee besides his studies. He contributes to his work with his experience in GIS and software engineering.

Frank Elberzhager, Dr., is an expert in the area of software quality assurance and a member in the department “Architecture-Centric Engineering” at the Fraunhofer Institute for Experimental Software Engineering IESE in Kaiserslautern. For more than ten years, he has been leading research and industrial projects of different size and criticality. One focus of his current research work relates to digital ecosystems in smart cities and rural areas.

Sebastian Erdmann, M.Sc., MBA, former scientific research assistant at the Jade Hochschule Oldenburg. Currently working as energy manager in a large-scale enterprise and CEO of GloW efficiency off-grid GmbH, which deals with solar equipment e.g. small scale PV-systems / “balcony-PV” and energy saving stoves.

Hans Erhorn, Dipl.-Ing. and Ing. (grad.), works as a principal adviser for the Fraunhofer Institute for Building Physics IBP and other institutions (e.g. KfW Entwicklungsbank). After his studies in supply and environmental engineering at the Berliner Hochschule für Technik (BHT) and the Technical University of Berlin, he worked as a scientific assistant at the department of Building Physics at the University of Duisburg-Essen and became head of the department of Energy Efficiency and Indoor Climate (formerly Heat Engineering) at Fraunhofer IBP from 1984 to 2018. From 1988 to 2015, he was also a lecturer at the University of Stuttgart. He has been active as the chairman of the DIN Joint Committee “Energetische Bewertung von Gebäuden” since its foundation and has realised over 250 demonstration buildings worldwide. In 2021, he was appointed as an expert member of the Climate Enquiry Commission of the Bremen Parliament.

Heike Erhorn-Kluttig, Dipl.-Ing., is a group leader and scientist at the Fraunhofer Institute for Building Physics IBP. After studying civil engineering at the University of Stuttgart, she first worked as researcher and since 1996 as group leader at Fraunhofer IBP. She is currently responsible for the group “Buildings –

Districts – Cities" in the department of Energy Efficiency and Indoor Climate. She was and is project manager of various national and international demonstration and evaluation projects as well as accompanying research projects.

Katrin Fahrenkrug studied geography and political science in Hamburg (1985) and mediation (M.A. 2007). She founded Institut Raum & Energie GmbH in 1989 and has been the managing partner ever since. Her main areas of activity include expert advice and process management of dialogue-oriented regional and municipal development processes. She has proven in the design and implementation of participation processes as well as the moderation, mediation and communication of political decision-making processes in different event formats.

Manfred Norbert Fisch, Univ. Prof. Dr.-Ing.,is head of the Steinbeis Innovation Centre energieplus (SIZ), Braunschweig and Stuttgart, general representative of EGS-plan Ingenieurgesellschaft, Stuttgart and co-founder and shareholder of Green Hydrogen Esslingen. After completing his studies in mechanical engineering with a focus on energy technology at the University of Stuttgart, he set up and headed the Department of Rational Energy Use and Solar Technology at the Institute of Thermodynamics and Thermal Engineering (ITW) and received his doctorate in engineering in 1984. As head of the department, he was involved in numerous R + D projects on the technical use of solar energy, providing forward-looking impulses. In 1996 he accepted the call to become a full professor at the TU Braunschweig and managed the Institute for Building and Solar Technology (IGS) for 22 years. During this time, more than 20 R&D projects were worked on in the fields of energy-efficient buildings, heat and cold storage, methods for optimising the operation of non-residential buildings, and the development and implementation of climate-neutral neighbourhoods. Since the beginning of 2020, the R&D projects have been continued in SIZ energieplus, an affiliated institute of the TU Braunschweig, under its overall management.

Jens Frank, Diplom Betriebswirt (FH), is an employee of the Institute for Applied Material Flow Management. After graduating from high school in 2002, he studied environmental and business administration at Trier University of Applied Sciences, successfully completing his studies in 2009 with a diploma (FH). Since 2009, Mr. Frank has been employed by the Institute and is active in the areas of project development, acquisition and management on behalf of or in cooperation with ministries, associations, municipalities and companies. He is the direct contact person for a large number of project partners and clients. In particular, he is responsible for project management, the selection of methodology and the control and monitoring of the results.

Daniel Franke, M.Sc., born in 1990, studied computer science from 2009 to 2015 with a focus on system development, graduating with a bachelor's and master's degree. From 2015 to 2018, he worked as an IT consultant. Since 2018, he has been working at the University of Applied Sciences Zwickau as a research assistant with a focus on software development, artificial intelligence and blockchain.

Rolo Fuetterer, Prof. Dipl.-Ing., is founder and director of Metropolitan Architecture Research Studio (MARS) and director of the Institute for Sustainable Building and Design (INBG) at Kaiserlautern University of Applied Sciences. He studied architecture and urban design at the University of Karlsruhe and Delft (NL). His teaching focus on sustainable urban planning and the holistic approach to urban design (Building-Infra-Landscape). His research focus on transformation of urban Typologies driven by aspects of sustainability.

Janika Gabriel, Dipl. Soz., is deputy managing director and research fellow at the BIS Berlin Institute for Social Research. She studied sociology at the Catholic University of Eichstätt-Ingolstadt with major subject methods of empirical social, market and opinion research. She has several years of experience in applied and empirical social research at the Statistical Of-fices of Saxony and Catholic University of Eichstätt-Ingolstadt. She was significantly involved in several projects in the fields of energy efficiency, user acceptance, health economic ac-counts, microcensus, population projection, mobility behaviour and social injustice.

Gunther Gehlert, Prof. Dr.-Ing., is Professor of Building and Environmental Technology at the Fachhochschule Westküste in Heide.

Henner Gimpel, Prof. Dr., is an industrial engineer and information systems specialist. He heads the Chair of Digital Management at the University of Hohenheim. Prof. Gimpel holds a leading position at the Research Center Finance and Information Management and is a member of the Project Group Business & Information Systems Engineering at the Fraunhofer Institute for Applied Information Technology FIT. In research, teaching and projects, he is concerned with the design, acceptance, use and impact of socio-technical information systems, especially in the context of healthcare management and industry.

Sebastian Gölz, Dr., Dipl.-Psych., is a psychologist and works as the head of the team User Behavior and field tests at the Fraunhofer Institute for Solar Energy Systems in Freiburg. His research interests are transdisciplinary transformation processes, investment decision for renewable energy technologies, analysis of user behavior in smart metering, variable tariff systems and flexible energy supply concepts, and acceptance of the energy transition.

Jürgen Görres, Dr., is head of the Energy Division in the Office for Environmental Protection of the State Capital Stuttgart. After studying process engineering and obtaining his diploma in 1989 at the University of Stuttgart, he worked there as a scientist at the Institute for Process Engineering and Steam Boiler Technology, which he completed in 1996 with a doctorate in the field of energy engineering at the University of Stuttgart. Since 1996, he has been employed at the Office for Environmental Protection of the State Capital Stuttgart: first as head of the section „heat management and energy concepts“ and since 2006 as head of the entire energy department. In this role, Dr. Görres is responsible for the development and implementation of the city's energy and climate protection concept. In doing so, it is a matter close to his heart to develop Stuttgart into a climate-neutral city. In addition, he is involved in various energy working groups (VDI, German Association of Cities and Towns, Council of European Municipalities and Regions) and leads several research projects in the field of energy and its efficient use.

Benny Gottschalk, Dipl.-Ing. (FH), is a research assistant at the professorship of Electrical Power Engineering / Renewable Energies at the Faculty of Electrical Engineering at the University of Applied Sciences Zwickau. After completing his vocational training as an electrical engineer specialized in automation technology and working as a senior fitter in systems engineering, he completed his diploma in electrical engineering in the field of energy technology with a focus on electrical energy storage systems. Since then he has been working in electrical power engineering, electrical energy storage, electromobility and mains protection within numerous research projects at the University of Applied Sciences Zwickau.

Valerie Graf-Drasch, Dr., is a postdoctoral researcher at the Chair of Digital Management at the University of Hohenheim. She is a member of the Project Group Business & Information Systems Engineering of the Fraunhofer Institute for Applied Information Technology FIT. Dr. Graf-Drasch holds a bachelor's degree in economics, a master's degree in finance and information management, and a doctorate in economics from the University of Augsburg. She primarily conducts research on topics related to socio-technical information systems and sustainability.

Torsten Grothmann, Dr., is an environmental psychologist and a senior scientist in the interdisciplinary Ecological Economics Group at the University of Oldenburg. His research focuses on social, psychological and methodological aspects of sustainability transformations, particularly on participation and communication with regard to climate change mitigation and adaptation.

Tobias Härtel, M.Sc., is a research assistant at the "Institute of Energy and Transport Engineering" at the University of Applied Sciences Zwickau. He holds a diploma from the University of Applied Sciences Zwickau in the field of "Supply and Environmental Engineering" with a major in "Supply Engineering/ Facility Management" and an M.Sc. degree from the same university in the study programme "Intelligent Building Infrastructures". At the research and transfer centre "Forschungs- und Transferzentrum e.V." at the University of Applied Sciences Zwickau, he works as a research assistant in the area of control and monitoring of thermal processes. He is currently employed as a research assistant at the chair of building climate technology / integral planning at the University of Applied Sciences Zwickau in the third-party funded project "ZED (Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau's Energy Transition)". In his research work, he deals with numerous topics in the field of future energy supply systems.

Holger Heible, B.A., has developed real estate projects for 20 years. He earned a diploma in Real Estate Management and a B.A. in Property and Facility Management, both from EBZ Business School, Bochum. He teaches project development, rental management as well as facility management at Europäische Immobilien Akademie in Saarbrücken.

Alexander Hill M.Sc. is a developer, researcher and PhD student in the group Energy-efficient Smart Cities at the OFFIS research institute.

Erik Höhne, M.Sc., has been a project worker for urban and neighbourhood development at the City of Zwickau in the research project ZED – "Demonstrating Zwickau's energy transition" since 2018. He studied geography with a focus on urban and regional development at the TU Dresden from 2008–2011 (Bachelor of Science) and 2011 to 2015 (Master of Science). Afterwards, he worked as an employee at the Spremberg municipal administration. He is a member of the Integrated Information Systems (AIIS) working group at the West Saxon University of Applied Sciences Zwickau.

Ilka Hoffmann is a research assistant at the FH Westküste University of Applied Sciences and a lawyer and mediator in Hamburg.

Steffen Hupp is a researcher in the "Digital Society Ecosystems" department at the Fraunhofer Institute for Experimental Software Engineering IESE in Kaiserslautern. He completed his Master's degree in Computer Science with a focus on Software Engineering at the Technical University of Kaiserslautern and has been working at Fraunhofer IESE as a software engineer since 2015. There he is responsible for the development and technical conception of mobile apps, cross-platform solutions, and (cloud-based) backend systems.

Patrick Huwig, M.Sc. industrial engineer, has been an employee of the Institute for Applied Material Flow Management since 2013. His work focuses on the creation of energy supply concepts and the design of zero-emission projects. He is the direct contact for a large number of project partners around the main topics of renewable energies, energy efficiency and supply strategies.

Micha Illner, M.Sc., worked as a research assistant at the Fraunhofer Institute for Building Physics IBP in the department Energy Efficiency and Indoor Climate. After completing his Bachelor's degree in building physics at the University of Stuttgart and a subsequent Master's degree in renewable systems and energy technology, he worked as a research assistant at the University of Stuttgart. He was then employed by Werner Sobek Green Technologies GmbH and finally started as a research assistant at the Fraunhofer Institute for Building Physics in 2014. In his research work at Fraunhofer IBP, he dealt with energy efficiency in schools, knowledge transfer and concepts for climate-neutral buildings and districts. Since the end of 2021, he has been working as a consultant in the area of Building Performance at Drees & Sommer SE.

Sebastian Junghans, M.Sc., studied Business Administration as well as Management and Systems Intelligence at the University of Applied Sciences Zwickau with a focus on business information systems. Since the beginning of his research activities, he has been involved in projects and publications on the topics of business intelligence, data science and machine learning as well as the application of innovative solution approaches. This includes, for example, the development of an automated, sensor-based recognition of activities of daily living within the home, the evaluation and analysis of machine data in real time, as well as the development of a live-stream clustering of sour lobes to control the machine. Currently, Sebastian Junghans is doing his doctorate on the topic of predictive intelligence using the example of forecasting customer orders in the metalworking industry.

Peter Klement, Dr., has been a research associate at DLR e.V. Institute for Networked Energy Systems since 2010 and researches management strategies for energy systems in the Energy System Technology department.

Sascha Koch is Professor for Computer Sciences with a Specialisation on Data Analysis at Jade University of Applied Sciences and has carried out application-oriented research, development and entrepreneurship in this field for about 25 years. Currently, Koch leads several research projects at the Institute for Applied Photogrammetry and Geoinformatics (IAPG) focusing on investigating complex, mostly spatially related questions based on data in order to support decision making and generate new knowledge from data, especially to contribute to the energy revolution.

Martin Kohl, M.Sc., Geography, is a staff member of the Institute for Applied Material Flow Management. Since 2018, Mr. Kohl has been a salaried employee of the Institute and is active in the areas of project development, acquisition and management on behalf of or in cooperation with ministries, associations, municipalities and companies. He is the direct contact person for a large number of project partners and clients. His area of responsibility includes in particular the topics of mobility, regional value creation and citizen participation.

Manoël Kraus, B.Sc., is a research associate in the Integrated Information Systems (AIIS) working group at the University of Applied Sciences in Zwickau. He holds a Bachelor of Science degree in Computer Science from the University of Applied Sciences. At AIIS, he works in the area of embedded systems, as well as building automation and ambient assisted living.

Daniel Kretz, Dr. rer. pol., studied computer sciences at the University of Applied Sciences in Zwickau and graduated with Dipl.-Inf. (FH) and M.Sc. degrees. After his studies he dedicated his first research in projects to automate offer and production planning using feature-based CAD drawings of machining parts. Subsequent projects dealt with virtualization technologies and virtual infrastructures e.g. to acquire measurement data from charge point stations for electric cars and accounting services, service implementation for data monitoring, analysis and evaluation in low-voltage grid of a city quarter as well as digitalization and automation of smart homes and smart residential buildings within smart city districts. In the course of the developments, the idea for generative generation of configuration and installation of smart flats and smart building in smart cities arose, thus linking both thematic worlds. At the same time, the elementary developments enriched the doctorate (Dr. rer. pol.) at the Chemnitz University of Technology with essential practical aspects in the field of optimization of supply infrastructures (Kretz 2021).

Uwe Krien, Dr.-Ing., is a post-doctoral researcher at the Department of Resilient Energy Systems at the University of Bremen. He works on sector-coupled energy system models and their interaction with the surrounding energy system. He is co-founder and developer of the open energy modelling framework (oemof). He received his diploma in energy engineering at the Technical University of Berlin.

Simeon Kühl, Dipl.-Ing., works in the Energy Division in the Office for Environmental Protection of the State Capital Stuttgart. After finishing his Diploma in Environmental Engineering at the University of Stuttgart, he has been working for several companies in the fields of energy and environmental sciences. Since 2019, he is working at the city of Stuttgart on the project „STADTQUARTIER 2050“.

Katrin Lenz works as Senior Researcher and project manager in the group "Sustainable Construction" of the department Life Cycle Engineering at the Fraunhofer Institute for Building Physics IBP in Stuttgart. As industrial engineer for real estate technics and management, she is involved in national and international projects related to sustainability assessment in building construction for more than 12 years. Her focus is on life cycle assessment (LCA) and life cycle costing (LCC) studies and decision support for energy-efficient buildings, respective technologies/services and energy-efficiency solutions for building supply as well as sustainable urban development. She is engaged with various initiatives such as the IEA EBC Annex 72 (Assessing Life Cycle Related Environmental Impacts Caused by Buildings) or the user advisory group of the German LCA database ÖKOBAUDAT.

Sven Leonhardt, M.Sc., born in 1983, studied business administration (Dipl.- Kfm.) with a focus on controlling and financial management at the University of Applied Sciences Zwickau (WHZ) from 2006 to 2011. From 2011 to 2014 he was a research assistant in the working group Integrated Information Systems (AIIS) of the WHZ. Parallel to this activity, he completed a master's degree in Management and Systems Intelligence (M.Sc.) at WHZ from 2012 to 2014. Since 2014, with a one-year interruption, he has been working as a project manager and project leader in scientific reallaboratory projects at the city of Zwickau with a focus on: Innovations and Transfer, Energy Transition, Ambient Assisted Living (AAL), Controlling and KPI Systems, Performance Management, Business Model Development, Business Process Integration and Technical Assistance Systems.

Silke Lorenz, Dipl.-Ing., is a research assistant at the Jade University of Applied Sciences in Oldenburg and is a member of the "Institute for Database-oriented Engineering". She has a teaching position for the subject "Building Information Modeling/CAD". She is also part of the department of urban water management.

Simon Marx, M.Sc. works as a research associate at the Steinbeis Innovation Center energieplus (SIZ) and as a project manager at the engineering office EGS-plan in Stuttgart. During his studies at the RWTH Aachen in the field of environmental engineering, he focused on energy and the environment in building sector. Since October 2016 it has been headed by Univ. Prof. Dr.-Ing. Manfred Norbert Fisch involved in the research and development of innovative district concepts. In addition to sustainable energy design, the focus is on the implementation of demonstration projects for sector coupling and green hydrogen.

Felix Mayer, M.Sc., has been involved in the implementation of the climate district since 2016. Initially, he worked for the overall coordinator of the research project, SIZ energieplus. Since 2019, he has been project manager at the operating company, Green Hydrogen Esslingen GmbH. Since 2021, Felix Mayer has been a lecturer for smart grid and sector coupling at the HFT-Stuttgart.

Benedikt Meyer, M. Eng., Benedikt Meyer is employed as a research associate at the University of Bremen in Faculty 4, Department of Resilient Energy Systems. Within the Quarree100 project, he heads the Infrastructures and Systems work area. He studied supply engineering and energy management for a Bachelor of Engineering at Baden-Wuerttemberg Cooperative State University. He then completed a master's degree in environmental technology at the university of applied science Amberg-Weiden and worked at Fraunhofer UMSICHT in the field of energy system analysis. Before moving to the university he headed the thermal energy storage group at Fraunhofer UMSICHT.

Eva Michely, PhD, is a PR professional and specialises in content writing. She earned a PhD in British literary and cultural studies from Saarland University. Her doctoral dissertation deals with the representations of politicised space in contemporary Northern Irish fiction and film.

Tino Mitzinger, M. SC., is employed as a research associate at the University of Bremen in Faculty 4, Department of Resilient Energy Systems. Within the Quarree100 project, his research focus comprises the functional and structural resilience of urban energy systems. He completed a master's degree in Energy- and Environmental Engineering at the Technical University of Hamburg.

Simon Moelller, M.A. completed his master's degree in sociology and economics at Ludwig-Maximilians-Universität in Munich in 2016. After two years of employment as a project supervisor at Arqum GmbH in environmental and energy management consulting, he joined the Institute of Sociology at LMU Munich in 2018 as a PhD student and research assistant. There he is part of the working group "Lokale Passung", which deals with various topics of sustainable development, climate protection and climate adaptation. Within the working group he is involved in the BMWK funded research project "ZED – Demonstrating the energy transition in Zwickau" as well as in the research project "EffKom – Energy efficient living comfort: User-oriented further development of an automated system for controlling room heating". In close cooperation with engineers and business informatics specialists, his interests lie primarily in user-oriented technology development and in-depth data analysis to investigate human-technology interactions and their effects on energy consumption.

Alexander Müller-Dollinger, M.Sc., studied energy technology at the University of Stuttgart and is currently doing his doctorate at the Institute for Energy Conversion and Storage (EWS) at the University of Ulm. He is working on the topic of intersectoral energy linkage with a special focus on mobility using high-pressure PEM electrolysis. He has been working at the Institute for Sustainable Energy Technology and Mobility (INEM) at Esslingen University of Applied Sciences within the research project "Climate-neutral urban district Esslinger Weststadt", which is funded by the BMWI and BMBF, since 2017. His main topic here is the investigation of the mobility sector within the urban quarter.

Dimitri Nefodov, M. Sc., is research associate at the Chemnitz University of Technology.

Martin Neuburger (Member, IEEE) received the B.S., M.S., and Ph.D. degrees in electrical engineering from Ulm University, Ulm, Germany, in 1998, 2000, and 2004, respectively. After working for the Robert Bosch GmbH, in 2011, he joined the University of Applied Sciences, Esslingen, Germany,where he is currently a Professor and the Head of the Department of Electrical Drives.

Tim Neumann, Dr. rer. pol., born in 1986, studied business administration at the University of Applied Sciences Zwickau from 2006 to 2010, majoring in corporate logistics and business informatics. After graduation, he started working as a research assistant at the Chair of Business Informatics and worked at the Chair of Networked Systems in Business Administration from 2015. In addition to working as a research assistant, he completed a master's degree in Management & Systems Intelligence (M.Sc.). In 2021, he successfully completed his doctorate at Chemnitz University of Technology on the topic of "Prozessverbesserung durch die Digitalisierung von Infrastrukturen". His research currently focuses on process management, ERP systems, digitalization, ubiquitous infrastructures, optimization of business models and processes, and infrastructure in an All Electric Society.

Anne Nieters, M.Sc. Economics, is scientific researcher at Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM (energy system analysis). She leads working group 5 (economic and legal analysis, business model development) of the research project QUARREE100. In this context, the results described in this report were developed.

Oliver Norkus works as CTO at embeteco GmbH & Co, KO. He studied Computer Science at the University of Oldenburg and holds a PhD in Computer Science.

Tobias Nusser, M.Sc., is an employee at the Steinbeis Innovation Centre energieplus (SIZ) and the company EGS-plan in Stuttgart in the position of deputy head of the energy conception department and as project manager. He studied mechanical engineering at Ulm University of Applied Sciences and Sustainable Energy (SENCE) at HfT Stuttgart. His work focuses on innovative energy concepts for buildings and districts as well as municipal climate protection concepts. He has been working for more than 10 years in numerous research projects in the context of buildings in the energy-plus or nearly-zero-energy standard as well as on issues of climate neutrality or achieving the energy transition goals at district and city level.

Mathias Oberhauser, Dipl.-Ing., studied Mechanical Engineering at the University of Kaiserslautern and then worked as research engineer on different topics in the central research and development of Zahnradfabrik Friedrichshafen AG in Friedrichshafen, Germany. Since 1991 he has been professor at Esslingen University of Applied Sciences in the field of simulation and control. His main topic is control of all kind of automotive driveline. He has been consultant of different automotive OEM's and major suppliers in powertrain simulations. Since 2013 he has been involved in the change of Esslingen's city bus towards electro-hybrid technology. In the frame of the research project "Climate-neutral urban district Esslinger Weststadt" he was doing research in the field of cross-sector energy supply and smart grids.

Christian Persohn, Dipl.-Ing. Maschinenbau (FH), is the owner of Ingenieur- und Gutachtergesellschaft Christian Persohn mbH. As an experienced energy efficiency expert and assessor for PV systems, he and his team oversee the development and integration of innovative components in the two existing buildings on behalf of the building owners and work at the interface with the scientists.

Christan Pieper M.Sc. is a senior developer in the group Energy-efficient Smart Cities at the OFFIS research institute.

Svenja Polst is a Digital Innovation Designer at Fraunhofer IESE. She mainly works in projects related to mobility, smart cities, and usable security and privacy. Svenja holds a degree in Human Factors and Engineering Psychology and applies the theories and experiences from this field to design digital solutions that lead to a good user experience.

Jana Rasch, Master of Science, has been working at the Development Agency Heide Region as Technical Coordinator in the QUARREE100 project since 2018. The focus of her work is on the technical implementation of the innovative energy concept. Through her interdisciplinary university studies in Green Energy at the West Coast University of Applied Sciences, she also supports the project in legal-regulatory and economic issues. In addition, she is working in the WESTKÜSTE100 project on issues related to the integration of large-scale electrolysis plants into regional infrastructures. On the basis of her Bachelor's degree in economics and law, she previously worked in the wind power industry in the operational and administrative areas of project development.

Mario Reichel, Prof. Dr.-Ing., is professor for Building Climate Technology / Integral Planning at the "Institute of Energy and Transport Engineering" at the University of Applied Sciences Zwickau. He holds a diploma from the Technical University of Karl-Marx-Stadt (now University of Technology Chemnitz (TUC)) in the field of "Air Conditioning and Drying Technology" with a major in "Building Services Engineering" and completed his doctorate at the University of Technology Chemnitz (TUC) on the subject of "Energy Saving through Presence Control". In addition to many years of work in building services engineering, he has been a professor of supply engineering at University of Applied Sciences Zwickau since 2005, a professor of technical building equipment and regenerative energy systems at University of Applied Sciences Dresden (HTW) since 2010 and has been back at the University of Applied Sciences Zwickau since 2019. Scientific activities include activities as a project leader in several research topics, publications and book contributions as well as the processing of diverse third-party funded topics. Currently, he is primarily in charge of the research project "ZED (Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau's Energy Transition)".

Anneka Ressel is assistant to the board of the building cooperative "Baugenossenschaft Überlingen eG". In her Bachelor of Science thesis written in 2019 at Biberach University of Applied Sciences, the topic "Energy justice tough neutral rent including heating and socially acceptable renovation" from the lighthouse project "Stadtquartier 2050" was taken up and pursued further in the years that followed. The focus of her work for the cooperative lies in the implementation support of sustainable energy concepts and management of funding projects.

Markus Richter, Univ.-Prof. Dr.-Ing., is head of the Professorship for Applied Thermodynamics at the Chemnitz University of Technology.

Alexandra Rode, M.A. Virtual Design, is a research assistant in the field of virtual design. For EnStadt: Pfaff she designs the central exhibition and the communication concept of the Reallabor. She researches the added value of virtual realities in communication processes and develops strategies that extend design and conception into virtual space through the use of various 3D software.

Janko Röbisch is an experienced software engineer at Tachycon. For over a decade he builts extensive know-how in developing evaluation tools for a wide range of financial products and risk management. Janko holds a Master of Science in theoretical physics from the Georgia Augusta, Göttingen.

Johannes Röder, M. Sc. is a PhD candidate and research associate at the Department of Resilient Energy Systems at the University of Bremen. He is researching on renewable and system-supportive district heating systems. Before, Johannes Röder worked as research associate at the Bavarian Center for Applied Energy Research (ZAE Bayern) in Garching. He holds a MSc in mechanical engineering and has working experience in geothermal district heating systems, energy efficient buildings, and energy system optimization.

Annette Roser, Dr., is Head of the Business Unit "Social Science Evaluation" at the Institute for Resource Efficiency and Energy Strategies, IREES in Karlsruhe. As a scientist, she has more than 20 years of experience in national and international projects. The focus of her work is on the sustainability of energy (production and use), studies on inhibiting and promoting factors of new energy-efficient technologies under economic and social aspects, implementation support for sustainability processes in the municipal and business sector, and evaluation of funding programs. Annette Roser is business coach (certified ACTP), member of the International Coaching Federation (ICF) and lecturer at the KIT in Karlsruhe on facilitation training.

Sven Rosinger, Dr.-Ing., has been a group leader in the Energy research department at OFFIS – Institute of Computer Science in Oldenburg since 2014. He and his research group Energy Efficient Smart Cities look especially at aspects of digitalization, which are becoming increasingly essential for the development of energy-efficient neighbourhoods and cities.

David Sauss, together with Prof. Dr. -Ing. Norbert Fisch, leads the Steinbeis Innovation Centre (siz) energieplus with locations in Braunschweig and Stuttgart which is established as a leading research institution for energy efficiency in buildings and quarters. His current focus is on hydrogen production and integration into the neighbourhood. After studying business administration in Greifswald and Braunschweig, he joined the Institute for Building and Solar Technology in 2003 as a research assistant. There, he conducted research on topics related to energy efficiency in buildings and quarters with a focus on monitoring and implementation of concepts. From 2011 to 2014, David Sauss worked in the Renewable Energy Systems working group at the Energy Research Centre in Lower Saxony. Since 2016, siz energieplus has been an affiliated institute of the Technical University of Braunschweig.

Ernst Schäfer, Dipl-Ing. M.A., works as scientific associate at “The Regional Planning and Environmental Research Group (ARSU)”. He is responsible for the conceptualisation, planning and realisation of real-world laboratories and participatory processes.

Judith Schäfer, Ass. jur., is the head of the Energy Law Department at the Institute for Climate Change, Energy and Mobility (IKEM). One of her research focus areas is the municipal and supra-regional planning of renewable energy plants and the corresponding approval procedures, particularly with regard to the simplification and acceleration of planning and approval procedures.

Karin Schakib-Ekbatan, Dr., works as a Senior Researcher in the Business Unit “Social Science Evaluation” at the Institute for Resource Efficiency and Energy Strategies, IREES in Karlsruhe. As a social scientist, she has more than 15 years of research experience in national and international projects in the field of sustainability and energy efficiency. Her focus in on human-environment interaction, such as energy-related behaviours or post occupancy evaluation in non-residential buildings. In the context of her dissertation, she developed a method for recording user satisfaction in the workplace as part of the German Assessment System for Sustainable Building (BNB). She is lecturer at the University of Koblenz and Landau (Factors Influencing Energy Use).

Oliver Scharf, Dipl.-Ing. (FH), studied automotive electronics and has since worked as a research assistant at the West Saxon University of Applied Sciences Zwickau. He is involved in the development of project-specific electronic solutions in the area of embedded computer systems, sensor systems and IoT as part of numerous research topics. The scientific topics include efficient heating control, ambient assisted living and micromobility.

Manuel Schaubt, Dipl.-Betriebswirt (FH), M.Sc. (International Material Flow Management), has been a freelance worker of the Institute for Applied Material Flow Management between Nov 2007 and Dec 2008 and an employee since Jan 2009. His work focuses on strategic material flow management and the design of zero-emission projects. He is the direct contact person for a large number of project partners around the main topics of renewable energies, electromobility, economic feasibility analyses, Life Cycle Assessment (LCA) and regional added value.

Ulrich Scheele, Dr., is adjunct professor for economic policy at the University of Oldenburg and project manager at "The Regional Planning and Environmental Research Group" (ARSU). ARSU GmbH. There he deals, among other things, with questions of planning and organization of infrastructure systems, their integration into the spatial context and with climate protection and climate adaptation strategies. In the Enaq project, he is involved in the planning and implementation of the real laboratory concept.

Teike Scheepmaker has a degree in Urban Planning (HafenCity University Hamburg, M. Sc.). He is an Associate Researcher at Institut Raum & Energie GmbH, where he designs and moderates numerous participation processes in the context of regional development (including the energy transition).

Sara Schierz, M.A. Environmental and Business Administration, has been an employee of the Institute for Applied Material Flow Management since 2012. Her work focuses on strategic material flow management and the design of zero-emission projects. She is the direct contact person for a large number of project partners around the main topics of energy and greenhouse gas balancing, economic feasibility analyses and evaluation of regional value-added effects.

Marvin Schnabel, M.Sc., is scientific assistant at the Jade University of Applied Sciences. He is working in the research project ENaQ – Energetisches Nachbarschaftsquartier Fliegerhorst Oldenburg. In this project he focused on spatial energy planning and thermal energy planning.

Michael Schneider, Dr., teaches and researches at the Department of Sociology at Ludwig-Maximilians-Universität on the topics of "Innovation, Risk Communication and Sustainable Development". After studying psychology and communication sciences, he worked as a project manager in market and social research and in management consulting. From 2006 to 2021, he was also Director at the bifa Umweltinstitut, responsible for the Strategy and Policy Consulting business area.

Lucas Schmeling has been working in various positions in the energy industry and project development since 2017 and is in parallel doing his doctorate at the DLR Institute for Networked Energy Systems on the optimisation of energy systems considering competing stakeholder interests.

Patrik Schönfeldt, Dr., is into efficient modelling of physical systems for computer algorithms. Since 2018 he does so as a research associate at DLR e.V. Institute for Networked Energy Systems. In 2021, he was elected spokesperson of the open energy modelling framework.

Johannes Schrade, Dipl.-Ing., is a senior scientist at the Fraunhofer Institute for Building Physics IBP in the department Energy Efficiency and Indoor Climate. After studying civil engineering at the Karlsruhe Institute of Technology (KIT), he worked as a research assistant at the chair of Building Operations and Building Technology at RWTH Aachen University. He has been a research associate at Fraunhofer IBP since 2008. In his research work, he deals with energy and climate protection concepts for buildings, districts and municipalities. He is an expert in energy balancing and thermal simulation of buildings and has in-depth knowledge of building physics, building services engineering and renewable energies.

Reiner Schütt, Prof. Dr.-Ing., is the vice president of the Westcoast University of Applied Sciences and responsible for controls, electric drives and grid integration. Prof. Schütt received the Diploma degree in Electrical Engineering from the University of Hannover in 1987 and started his career as a R&D engineer in the department of power electronics at the University of Hannover, where he received his Doctoral degree in 1992. He worked for several years as a technical director at ENERCON Nord Electronic GmbH and then joined the Westcoast University of Applied Sciences in 1998 as a professor for electrical drives and controls.

Eva Schulze, Dr. phil., Dipl. Soz., Dipl. Inn.-Arch., is managing shareholder and scientific director of the BIS Berlin Institute for Social Research. She studied interior architecture at Academy of Fine Arts, Munich, social sciences at FU Berlin and received her doctoral degree from TU Berlin. She was principal investigator of about 50 different social research projects about the impact of the Second World War on families, families in the German Democratic Republic, the impact of the Peaceful Revolution on life courses, transformation processes, the impact of ambient assisted living technologies on everyday life. She is an expert on technology assessment, demographic development, family and women studies, gender research, life course research, and gerontology. She was visiting professor at University of Vechta and research fellow at Yale University.

Martin Schwind, Dipl.-Ing. (FH), is a research assistant at the Forschungs- und Transferzentrum e. V. at the University of Applied Sciences Zwickau. After studying "Supply and Environmental Engineering at the University of Applied Sciences Zwickau, he worked on research topics on the technical utilisation of biogenic residues in a commercial enterprise. In his current position as a research assistant at the University of Applied Sciences Zwickau and the research and transfer centre "Forschungs- und Transferzentrum e.V.", he is working on research focusing on air conditioning close to the body, vertical greening and the development of innovative energy supply systems.

Bernd Siebenhüner, Prof. Dr., is professor for ecological economics at Carl von Ossietzky University of Oldenburg, Germany since 2007. He held prior positions at the Potsdam Institute for Climate Impact Research (PIK), Harvard University, and the Nelson Mandela University, South Africa. In his current research, he focusses on climate adaptation governance, participatory processes and transdisciplinarity, social learning, and the role of science in global environmental governance.

Melissa Siegl, B.Sc., is working as project manager for energy, environmental and climate protection at the city planning department of the city of Überlingen. After finishing her university degree in „sustainable regional management" at the University of Applied Forest Sciences Rottenburg, she is working at the city of Überlingen on the „STADTQUARTIER 2050" project.

Stefan Staehle, Dr.-Ing., is assistant director of the Institute for Sustainable Building and Design at Kaiserslautern University of Applied Sciences. He studied architecture and urban planning at the University of Stuttgart, where he earned his doctorate at the Institute for the Principles of Modern Architecture and Design. His teaching and research focus on systemic sustainability strategies in urban neighborhoods and their effects on the organization and structure of planning processes.

Martin Struve, Bachelor of Engineering, worked as a project engineer for energy plant construction and property manager in the semiconductor and aerospace industry in Hamburg after his mechanical engineering studies. His work focused on optimising existing supply and disposal structures and implementing new technologies in existing systems with a focus on energy saving and sustainability. After joining the Development Agency Heide Region, he was involved in the development of the energy concept for the QUARREE100 research project and is preparing the implementation of the project in the neighbourhood. At the same time, he is responsible for managing a district heating company for the extraction and distribution of waste heat from the Heide refinery.

Gerhard Stryi-Hipp, Dipl.-Phys., heads the Smart Cities group at the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg. He was Managing Director of the German Solar Industry Association for 15 years and has been working scientifically at Fraunhofer ISE since 2009. With his research group, he elaborates energy concepts for climate-neutral cities and neighbourhoods and develops methods for their creation. He coordinates interdisciplinary cooperation in Living Lab projects and is the scientific director of the project EnStadt:Pfaff.

Torben Stührmann, Dr. rer. nat., received his PhD in 2009 at the Max Planck Institute for Marine Microbiology on microbial detoxification mechanisms in marine oxygen minimum zones. He then worked as a post-doc at the Helmholtz Zentrum in Munich. In the context of his molecular biology work, he has made research stays in the USA and Israel. Since 2012 he has been working at the University of Bremen, focusing on socio-technical transformation research and resilience in various projects of transdisciplinary energy and sustainability research. Since mid-2018, he has been acting team leader of the Department of Resilient Energy Systems at the University of Bremen.

Phil Stüpfert is a scientific researcher at the Fraunhofer Institute for Experimental Software Engineering IESE in the Digital Innovation Design department. As a Digital Innovation Designer, he mainly focuses on the development and implementation of urban information and communication technology systems, as well as lean prototyping environments.

Arne Surmann, M. Sc. is a research associate at the Fraunhofer Institute for Solar Energy Systems ISE, Germany. He is doing research on decentralized energy management systems and their application in energy communities. His special interests are the design of connecting incentive mechanisms, market design, and the use of smart contracts in a non-trustful decentralized environment.

Tobias Teich, Prof. Dr. rer. pol. habil. Dr.-Ing., born in 1966, studied computer science with a focus on theoretical computer science and artificial intelligence at Chemnitz University of Technology from 1987 to 1992. From 1992 to 1995, he completed postgraduate studies in economics with a focus on production management and marketing, and from 1995 to 2002, he completed a master's degree with a major in vocational education at the Chemnitz University of Technology. From 2002 to 2015, he held a professorship in business informatics at the University of Applied Sciences in Zwickau. Since 2015, he has held the professorship for Networked Systems in Business Administration, in particular Energy Management, at the University of Applied Sciences Zwickau. In 2010, he founded the Integrated Information Systems Working Group (AIIS), which he has headed ever since. Research interests include ERP systems, software engineering, process management, energy management, building automation and ubiquitous infrastructures.

Florian Tischer, M.Sc., heads the Energy Management division at Polarstern GmbH and deals with the topic of portfolio management in the field of renewable energies and decentralised energy supply projects. He supports the "Neue Weststadt Esslingen" project in the development of the control strategy.

David Unland has a degree in Geosciences (University of Münster, B. Sc.) and Digital Media (University of the Arts Bremen, M. A.). He is Associate Researcher at the Department for Resilient Energy Systems, University of Bremen, where he develops tools with interactive media for sociotechnical participation processes in the Energy Transition.

Thorsten Urbaneck, Prof. Dr.-Ing. habil., is leader of Division Thermal Energy Storage, Professorship Technical Thermodynamics at the Chemnitz University of Technology.

Manuel Utz, is a researcher and PhD candidate at the Faculty of Law, Business and Economics at the University of Bayreuth, Germany. His research focuses on the design and implementation of blockchain-based applications in energy markets.

Dominikus Vogl, Dr. rer. soc., Dipl. Soz., is research fellow at the BIS Berlin Institute for Social Research. He studied sociology at LMU Munich, worked as research assistant at University of Cologne, University of Bern and was research fellow at Michigan State University and re-ceived his doctoral degree from University of Bern. He monitored and conducted national and international survey projects measuring environmental concern and risk perception.

Johannes Walbrunn, M.Sc., works at Consolinno Energy in the area of project planning, optimisation and simulation and has been leading the "Neue Weststadt Esslingen" project for the creation and optimisation of schedules for the smart grid since 2019. Together with the partners of Green Hydrogen Esslingen and Polarstern, he has set himself the goal of sustainably supporting and advancing the energy transition.

Katja Walther, Dr., took up her post with the City of Esslingen in 2015. After heading the section of Sustainability and Climate Protection with the urban planning office for six years, she was assigned the lead of the recently launched department Sustainability and Climate Protection in 2022. Fr. Dr. Walther's educational background includes pedagogical training as well as a doctorate in natural sciences with an emphasis on the impact of climate change on ecological systems.

Heiko Waurisch, B.Sc., is employed as a research associate at the Institute for the Transformation of the Energy System of the Westcoast University of Applied Sciences. Within the Quarree100 project, he is primarily concerned with automation technology and the automation concept and also contact name in this area for the Westcoast University of Applied Sciences. He studied Electrical Engineering and Information Technology at the Westcoast University of Applied Sciences. He then worked in the chemical industry with the task area plant automation, electrical planning and construction.

Lukas Wechselberger, is a student assistant at the professorship of Electrical Power Engineering / Renewable Energies at the Faculty of Electrical Engineering at the University of Applied Sciences Zwickau. After graduating from the Higher Technical Federal Training and Research Institute in St. Pölten (Austria) with focus on electrical engineering, he studied electrical engineering at the University of Applied Sciences Zwickau, specialized in energy technology. Since this time, he has been working in a variety of research projects, mainly focusing on load and photovoltaic forecasts.

Steffen Wehkamp, M.Sc. B.Eng., has been a research associate since 2016, first at Osnabrück University of Applied Sciences, then in the Energy research department at OFFIS – Institute of Computer Science in Oldenburg. In Sven Rosinger's group, he researches energy business models.

Maren Wesselow, M.Sc. Sustainability Geography and Regional Development, works as scientific associate in the Ecological Economics Group at the University of Oldenburg. Within the ENaQ project, she accompanies and evaluates participatory formats.

Lennart Winkeler, studied Engineering and Management – Production Engineering (M. Sc.) at the University of Bremen. As a research associate at the Department for Resilient Energy Systems at the University of Bremen he focuses his research on Agent-Based Models for socio-technical systems and the support of a resilient energy transition by interactive decision support tools.

Andreas Wojta, Dipl.-Ing., has been head of the Building and Planning Department of the municipal of Heide for 5 years. This department brings together the strategic focal points of urban planning, building and energy management and infrastructural development, as well as the function as the lower building supervisory authority. Prior to that, he spent more than 14 years as head of the technical equipment department, overseeing federal construction measures and state construction measures in the state of Schleswig-Holstein (SH). In addition, he implemented the technical fields of study of the industry-accompanied studies in the company. Before moving to the municipal sector, he was also the deputy head of the federal construction division of the state of Schleswig-Holstein for 6 years. Before that, he worked for 6 years in a planning office with real estate management in the Bremen area.

Jens Wotte works as senior software engineer for embeteco GmbH & Co. KG. He studied Computer Science at the University of Oldenburg.

Shengqing Xiao, Dipl.-Ing., is research associate at the Chemnitz University of Technology.

Pauline Ziegert, M.Sc., has been a project employee in the transfer project ExPEERienceEUROPE at the City of Zwickau since 2021. She studied “Management of Public Tasks” (Bachelor of Arts) and “Project and Consulting Management” (Master of Science) at the University of Applied Sciences Zwickau from 2017–2021. In addition, she is a member of the working group Integrated Information Systems (AIIS) of the University of Applied Sciences Zwickau.

Joris Zimmermann, M.Sc. is a research assistant at the Steinbeis Innovationszentrum energieplus in Braunschweig.

Jörn Zitta, M.A. Sociology of Media and Culture, is a research associate at the Institute for Sustainable Building and Design at Kaiserslautern University of Applied Sciences. He studied social sciences and sociology of media and culture at the University of Trier. He conducts research on user needs, citizen participation and media communication in the context of sustainable planning processes of cities and neighborhoods.

Sven Rosinger, Steffen Wehkamp, Georg Blum

1 Presentation of the "ENaQ" Energy Transition Lighthouse

Summary: This presentation aims to give an overview on the developments on the former Fliegerhorst air base in Oldenburg, the developments towards the "ENaQ – Energetic Neighbourhood Fliegerhorst Oldenburg" project focussing on the Helleheide district and on the claim and further development of this district towards a living lab for a participatory co-creation process beyond the ENaQ project.

This presentation further highlights references of the project objectives to funding policy objectives and motivates the upcoming project related book chapters that can be allocated in the domains 'physical infrastructure', 'data basis and planning tools' and 'social science'. It further lists all network partners involved in the project and mentions generic obstacles the project had to cope with and its success factors.

1.1 Energetic Neighbourhood District as a Building Block of the Smart City Strategy in Oldenburg

1.1.1 A New City District is Emerging

With the cessation of flight operations at the Fliegerhorst air base in 1993 and the end of military use in 2006, the city of Oldenburg was given the opportunity to acquire a site of around 193 hectares. The former air base on the north-western outskirts of the city covers a total of 309 hectares, of which 116 hectares are allotted to two neighbouring communities and 193 hectares to the city of Oldenburg. The area of the city of Oldenburg is divided into the barracks area, the hangar crescent and a part of the airfield including the runway. On the airfield, a photovoltaic system extends to the areas of the neighbouring municipalities. The barracks area and the hall crescent are characterised by a building/hall stock dating from the 1930–1980s, part of which is to be preserved to maintain the character of the air base.

The development of this special area represents an important urban development task for Oldenburg in the coming years. The development of the site is intended to

Sven Rosinger, OFFIS e.V. – Institute for Computer Science, R&D Devision Energy, Escherweg 2, 26121 Oldenburg, e-mail: sven.rosinger@offis.de
Steffen Wehkamp, OFFIS e.V. – Institute for Computer Science, R&D Devision Energy, Escherweg 2, 26121 Oldenburg, e-mail: steffen.wehkamp@offis.de
Georg Blum, Oldenburger Energiecluster OLEC e.V., Marie-Curie-Strasse 1, 26129 Oldenburg, e-mail: georg.blum@energiecluster.de

https://doi.org/10.1515/9783110777567-001

Figure 1.1: Smart Citiy Living Lab Oldenburg.
(Source: Stadt Oldenburg, Jens Gehrcken)

meet the increasing demand for housing, especially for families and people with medium to low incomes. A total of about 1000 residential units and additional commercial units are to be built. In doing so, it is an important goal not to lose sight of the long-term and future-oriented development and to combine it with the timely needs of society and the economy. The guiding goals of urban development in this context include the creation of urbanity through concentration, mixture and density, the development of urban open spaces and the promotion of technologies as a driver of economic and urban development.

To meet the diverse requirements, the city of Oldenburg decided for a participatory process that involved citizens, the administration and experts on various topics of urban and neighbourhood development. At the beginning of 2015, a collection of ideas was launched, giving all interested parties the opportunity to submit their proposals for the subsequent use of the air base. Based on this, a one-week urban workshop took place on the grounds of the air base in June 2015, from which 10 guiding principles for the development of the area emerged and which can be viewed in detail in the master plan.[1]

Within the next major participation phases, the variants were presented to all participants in innovation camps and intensively discussed on the plan and model, advantages and disadvantages were worked out and working instructions were formulated. This process was presented to the Urban Planning and Building Committee and thus played a decisive role in shaping the master plan. Already at this time, an experimental district on the air base, a "Smart City Lab" which was named Helleheide, was planned.

1 Oldenburg Fliegerhorst masterplan document. Available at: http://www.oldenburg.de/fileadmin/oldenburg/Benutzer/PDF/Fliegerhorst/Masterplan_Fliegerhorst.pdf (Accessed: 6 April 2022).

1.1.2 Smart City Strategy of the City of Oldenburg

Parallel to the development of the master plan, the city of Oldenburg commissioned the OFFIS research institute to create a vision for Smart City. In this vision, the development of the Smart City Laboratory on the air base was concreted together with representatives of the economy, research and administration sectors and the idea of a Smart City was extended to the entire city area. For the development of the city of Oldenburg into a Smart City, the stakeholders defined a Smart City as follows: A "Smart City" comprises different focus areas that contribute to make the city more sustainable, more efficient, more liveable and fit for the future in a holistic development concept.

Oldenburg's development is based on the guiding principle "Focus on people". This means that the applications and solutions to be developed in the Smart City context should have a concrete benefit for the people, which does not necessarily include the entire population or is of a technical nature. Instead, target group-specific solutions should be defined. However, it must be ensured that a Smart City provides solutions for all population groups and that there is no claim to exclusivity. Citizens, associations, organisations, companies and research institutions should continue to be involved in the process and solutions should be developed, tested and evaluated together. However, the identity of the city and its districts is to be preserved through the Smart City applications.

The redevelopment of the air base offers the city of Oldenburg a unique opportunity to position itself as a pioneer for the development of Smart City concepts for comparable municipalities and cities in Germany and Europe. As a declared goal of urban development policy, a section of the air base has been designated as a "living" laboratory for testing new smart city technologies, including in the domains of energy, mobility and health, and is to be equipped with forward-looking infrastructure that is yet to be developed. This allows for a close integration and joint suitability testing of a multitude of technologies, which have currently been developed mostly in isolation by numerous stakeholders and could only be tested in parts.

The project "Energetic Neighbourhood", which was initiated by a consortium, is the first project in the area of neighbourhood development, energy and sector coupling. For the project, 21 predominantly regional partners from business, science and administration have joined forces to form the project consortium. In the future, it should be possible to realise further projects on the site. Therefore, it is necessary to create the right conditions for a sustainable design of the living laboratory already now.

Project Development "ENaQ – Energetic Neighbourhood Fliegerhorst Oldenburg"

The first project to emerge from the smart city strategy was the joint project "ENaQ – Energetisches Nachbarschaftsquartier Fliegerhorst Oldenburg". It was successfully applied for as part of the funding for research, development and demonstration in the field of energy-efficient buildings and neighbourhoods in the funding initiative “Solar Construction/Energy Efficient City” and is jointly funded by the Federal Ministries of Education and Research (BMBF) and Economic Affairs and Climate Action (BMWK) as part of the 6th Energy Research Programme.

Within the framework of this project, the living laboratory offers the opportunity to develop and directly evaluate services and added values for residents during the digitalisation of the energy transition through its permanent practical implementation and operation.

During the realisation of the residential district with about 110 residential units, the energy forms electricity and heating are integrated into a local multimodal energy system. The resulting neighbourhood concept, also called “energetic neighbourhoods”, represents a network of producers and consumers that are spatially close to each other and convert and store their surplus energy into other forms of energy or provide it directly so that neighbouring consumers can use it. The concept pursues the idea of increasing energy efficiency by avoiding “waste energy” and aiming to maximise local consumption of “neighbourhood” generated energy. In addition to sector coupling, an open, secure and privacy-compliant digital platform is being developed that allows citizens to access energy-related and non-energy-related added-value-services.

In addition to these two technical prerequisites for the emergence of sustainable energetic neighbourhoods, research is also being conducted into the social and economic interrelationships of the actors. Citizen acceptance and citizen-oriented cooperation and business models will ultimately be decisive for the long-term success of climate-neutral energy supply from self-generation plants at neighbourhood and district level.

Against this background, the project addresses the following questions:

– How must a local energy exchange in a neighbourhood be designed from a social and economic point of view to achieve a high level of acceptance among residents, owners of the generation units and service providers, and to be socially attractive and economically viable in the long term?
– What minimum requirements must the physical infrastructure meet to make the energy flows of the multimodal supply network automatable and optimisable with the aim of minimising CO_2 and to be applicable in existing neighbourhoods?
– How must a digital platform and its communication with system owners/prosumers be standardised and how can incentive models for the participation of neighbourhood residents look like to enable a quick and inexpensive establishment of e.g., energy cooperatives in many existing neighbourhoods?

The interdisciplinary project consortium, composed of all relevant sectors with municipal participation, includes an energy supplier, a grid operator, ICT companies, R&D institutes and universities, component and system manufacturers, renewable energy equipment suppliers, a housing association and an innovation network.

With the development of the master plan for the air base, a robust urban-spatial concept was designed, considering the existing building and open space structures and the development of a sustainable water and energy concept.

1.2 Reference to Funding Policy Objectives

To conduct research to gain technological progress or scientific foundations for understanding a challenge, the government provides funds from the federal budget. These research funds are allocated to various research topics. For example, the field of energy policy developed in the 1970s, and the first Energy Research Program (ERP) was adopted in 1977. Such research programs describe the goals, challenges and strategy and call for research to be conducted in these areas. In addition, eligible fields are described in which research projects can apply. This takes place in the so-called research calls.

While in the ERP 1–5 the focus was clearly on fossil and nuclear energy sources, the necessary basic research for renewable energies has already been carried out so that these have reached the level of industrial mass production. The goal of the German government is to achieve a sustainable energy system. This is reflected in §1 (1) of the Energy Economy Law. With the **amendment** to § 1 (1) of the Energy Economy Law in 2011, the research focus also changed:

> *The purpose of the law is to ensure the most secure, affordable, consumer-friendly, efficient and environmentally compatible grid-based supply of electricity, gas and hydrogen to the general public,* ***increasingly based on renewable energies.***

After this addition, finite energy sources were almost completely phased out in the 6th and 7th ERP (Figure 1.2). Building on the renewable energy research, the 6th ERP and the so called SINTEG projects, examined the economic potential of business models. The focus was to investigate the potential outside the current regulatory environment and its limitations.

In contrast to 6th ERP, is supposed to investigate innovative concepts under realistic conditions. This is being done through the 7th Energy Research Program. Within the research, it is important to support the stakeholders appropriately from basic research to market maturity. The respective topics are addressed in so-called modules. The first module is called Solar Building and aims at projects that show the way to climate-neutral building stock. Special focus is on multi-storey housing and a transition that is affordable for the stakeholders.

The project ENaQ aims at module II: Energy-efficient city and lighthouse projects – living laboratory neighbourhood. This module promotes projects that develop a long-term and energetically sustainable urban development at the level of the district. The energy sectors are to be coupled and renewable energies are to be integrated. For this purpose, the concept of energy management is referred to.

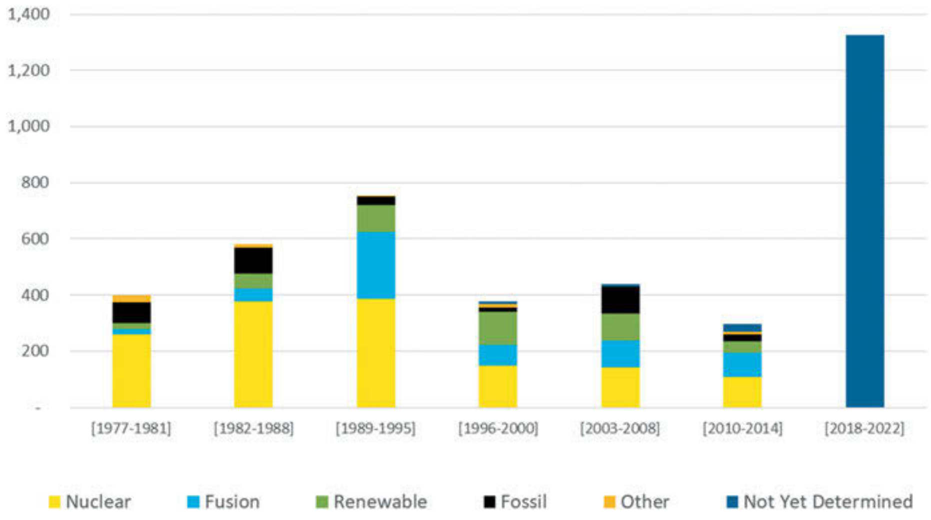

Figure 1.2: Average Yearly Research Budget for each German Energy Research Programm in thsd. € (inflation adjusted).
(Source: BMWi 2017, 2018)

Within this module, the three topics, 1. energy infrastructure, 2. data basis and planning tools, and 3. social science issues are to be investigated for the system neighbourhoods.

1.3 Motivation of Project Related Book Chapters

In parallel, the project structure of ENaQ was chosen to address these three topics. Therefore, the ENaQ project was divided into the subprojects Physical Infrastructure, Digital Platform and Business Model Development, and Participation. In this paper, we remain consistent with this structure, so that the chapters have been divided into these categorizations.

Figure 1.3. shows the structure of the chapters from the ENaQ project. The figure was designed in such a way that the topics were classified in the physical, social and interoperable dimensions. This helps to understand the real environments and connecting points of these topics.

A central role is held by the participatory design for researching social and business aspects of local energy cooperatives. This subproject covers all activities related to stakeholder participation, knowledge and technology transfer, acceptance research, and sustainability assessment, from conception to implementation and evaluation. The participatory design thus represents the interface between the technologically

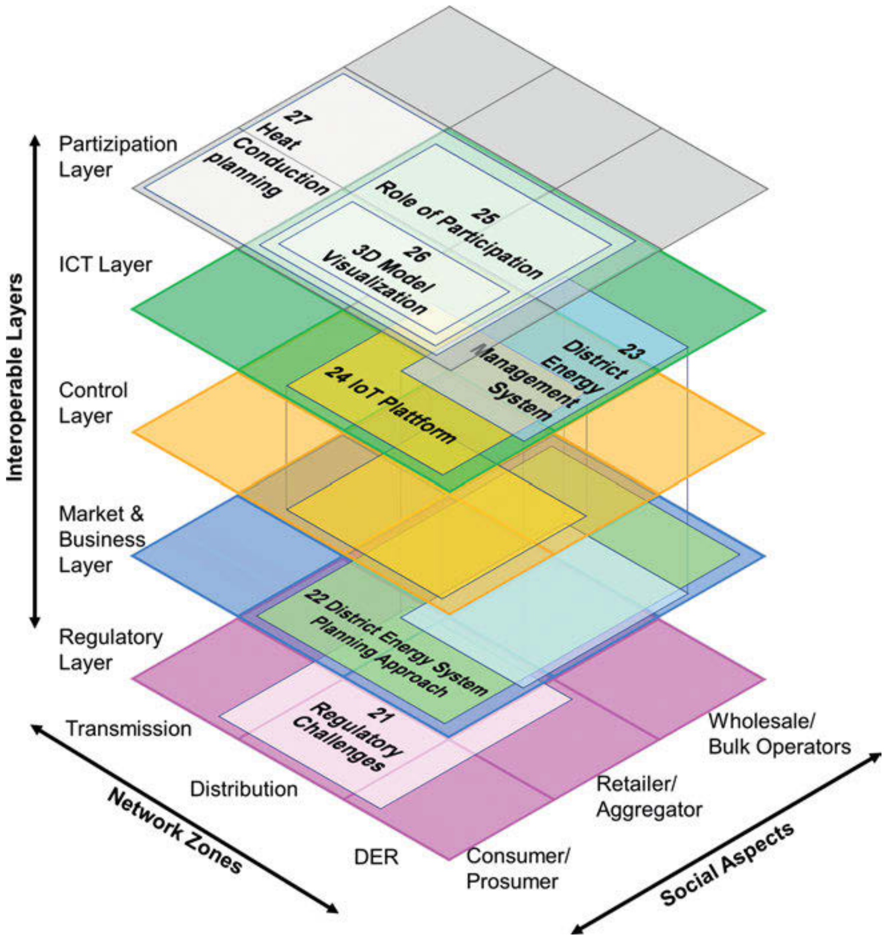

Figure 1.3: Chapter overview.
(Source: own representation based on Santodomingo/ Uslar/ Gottschalk et al. 2016)

driven external subprojects for the physical/multimodal and thus energy carrier-coupling infrastructure on the one hand, and the digital service platform as a tool for the low-cost/scalable implementation of local energy cooperatives and business models to be tested on the other.

1.3.1 Physical Infrastructure

Chapter 2 “Regulatory and Legal Challenges for District Energy Systems in Practice and Research” addresses the regulatory challenge for the physical infrastructure of decentralized projects. It lies in the uncertainty of legal classification and regulatory burden for such projects. The basis of the infrastructure phase lies in the assessment of on-site energy needs and local conditions, such as geothermal usability.

On this basis, chapter 3 “Multi-objective Design Optimisation of District Energy Supply – The Influence of Different Domestic Hot Water Concepts” presents a tool for the design of energetic supply of districts. The study deals with the multidimensionality of the solution finding, which was divided into a sizing and operation optimization.

1.3.2 Data Basis and Planning Tools

The level of detail of the simulations from chapter 3 was used to build a system for the operational management of energy generation and energy storage systems. The software architecture of the district energy management system is presented in chapter 4 “District Energy Management Scheduling using a Participatory Local Energy Market”. This software is built by connecting to the Internet of Things (IoT) and cloud technology.

The data basis is the IoT layer from chapter 5 “Establishing a Smart City Data and Interoperability Platform”. The digital platform is being developed with the aim of using it for various use-cases. The IoT layer is thus the foundation for further platforms such as: DEMS, community platform or a service platform. Due to the different application areas, the IoT layer is subject to interoperable requirements.

1.3.3 Social Science

Due to the focus of the ENaQ research project on the area of participation, all areas of the urban development project were brought to the public and discussed there. Chapter 6 “The Role of Citizen Participation in Developing a New Energetically Efficient Quarter – Limitations and Success Factors” presents the holistic approach of participation and the lessons learned.

Chapter 7 “Mixed Reality Systems in the Participation in Urban Land Use Planning” uses the data of the IoT platform from chapter 5 to use mixed reality systems for participation. The quality of the results of participation often depends on the idea of the project and the goals. Mixed reality systems thus support the territorial imagination of the neighbourhood.

The acceptance is a critical parameter for many planners of heat networks. This problem is addressed in chapter 8 “Participatory Processes in Geodata-Based Thermal Energy Planning”, which presents a geodata-based survey to assess the suitability of areas for heat networks. This survey adds a social aspect to the survey, which is achieved through interaction with end users.

1.4 Network Partners in ENaQ

ENaQ is embedded in the Solar Building/Energy Efficient City funding initiative as one of six funded projects in Germany. Twenty one partners from research and industry form the ENaQ team, led by OFFIS Institute for Information Technology (see Table 1.1).

Table 1.1: Partners of the ENaQ team.

	Short Name	Full Partner Name	Address	
1	OFFIS	OFFIS e.V.	Escherweg 2	26121 Oldenburg
2	Stadt Oldenburg	Stadt Oldenburg (Oldb)	Büro des Oberbürgermeisters	26105 Oldenburg
3	EWE NETZ	EWE NETZ GmbH	Cloppenburger Str. 302	26133 Oldenburg
4	KEHAG	KEHAG Energiehandel GmbH	Im Technologiepark 4	26129 Oldenburg
5	BTC	BTC Business Technology Consulting AG	Escherweg 5	26121 Oldenburg
6	SCHULZ	SCHULZ Systemtechnik GmbH	Schneiderkruger Str. 12	49429 Visbek
7	GSG	GSG OLDENBURG Bau- und Wohngesellschaft mbH	Straßburger Straße 8	26123 Oldenburg
8	DWG	Deutsche WindGuard GmbH	Oldenburger Str. 65	26316 Varel
9	embeteco	embeteco GmbH & Co. KG	Marie-Curie-Str. 1	26129 Oldenburg
10	JungeHaie	Junge Haie GmbH	Alexanderstraße 184	26121 Oldenburg
11	ESP	ELECTRIC-SPECIAL Photronicsysteme GmbH	Ehnkenweg 13	26125 Oldenburg
12	Quantumfrog	Quantumfrog GmbH	Marie-Curie-Str. 1	26129 Oldenburg
13	NPP	New Power Pack GmbH	Kopernikusstraße 23	49377 Vechta
14	ANLEG	Anleg GmbH	Am Schornacker 59	46485 Wesel
15	ARSU	Arbeitsgruppe für regionale Struktur- und Umweltforschung GmbH	Escherweg 1	26121 Oldenburg
16	Uni Vechta	Universität Vechta – Fach Wirtschaft und Ethik	Driverstraße 22	49377 Vechta
17	Uni Oldenburg	Carl von Ossietzky Universität Oldenburg, Department für WiRe (BWL und Wirtschaftspädagogik)	Ammerländer Heerstr. 114–118	26129 Oldenburg
18	IFAM	Fraunhofer-Institut für Fertigungstechnik und angewandte Materialforschung	Wiener Straße 12	28359 Bremen

Table 1.1 (continued)

	Short Name	Full Partner Name	Address	
19	Jade HS	Jade Hochschule, Institut für Angewandte Photogrammetrie und Geoinformatik & Institut für Datenbankorientiertes Konstruieren im Ingenieurbau	Ofener Str. 16/19	26121 Oldenburg
20	OLEC	Oldenburger Energiecluster OLEC e.V.	Marie-Curie-Straße 1	26129 Oldenburg
21	DLR VE	Deutsches Zentrum für Luft- und Raumfahrt, Institut für Vernetzte Energiesysteme	Carl-von-Ossietzky-Straße 15	26129 Oldenburg

1.5 Future Steps and Vision of Participatory Co-Creation in Helleheide beyond the Project

Oldenburg. Air Base. Helleheide. Our Neighbourhood, where Research is at Home

One of the central goals pursued with ENaQ is to create a research environment in the Helleheide neighbourhood that facilitates follow-up projects by actors from business, science and civil society. This idea of the Smart City Living-Lab was already anchored in the creation of the master plan for the Oldenburg air base. What does this mean? Companies and actors from research and science and civic initiatives can – within the framework of their projects and for a limited period of time – test products, services or applications on site under real conditions. The active involvement of the residents in the implementation makes this project special. The project initiators thus benefit directly from the testing of their project by the local residents.

The overriding aim of the projects in Helleheide is to implement ideas and follow-up projects in the sense of innovative and sustainable neighbourhood development. The implementation takes place in and with a lively neighbourhood in which the residents themselves can and should exert creative influence. In this way, joint projects can be initiated that meet with a high level of acceptance among the residents. Overall, the aim is to achieve a high added value and to contribute to the transferability of future neighbourhood development.

Diverse. Communal. Inventive

The thematic areas in which projects can be located are wide-ranging: from projects in the fields of energy or mobility to offers in the context of health and infrastructure to community-building activities and educational topics, many things are possible and desired that fit into an innovative and sustainable neighbourhood development in a lively neighbourhood. Helleheide should be available as an experimental and testing ground for technical and non-technical innovations, communal housing projects, novel supply and mobility concepts at neighbourhood level. The aim is to integrate Helleheide beyond the boundaries of the neighbourhood into the Fliegerhorst district, and into Oldenburg’s city centre and the surrounding area. This can and should contribute to (re)questioning the role of the neighbourhood, for example regarding mobility needs, local supply facilities or urban working.

The resources available in the neighbourhood for the implementation of follow-up projects are quite heterogeneous and include:

1. technical space – for the construction and operation of technical facilities and other applications
2. residential buildings – for connection to and testing by residents in the neighbourhood
3. open spaces and traffic areas – for alternative mobility offers and social interaction and community building
4. energy laboratory – as a remote test stand for the simulation of systems in real operation
5. digital platform – for the connection of facilities and services in the neighbourhood

Target groups for follow-up projects are stakeholders from business, science and civil society, who can act as multipliers to further Helleheide’s goal or contribute new ideas to the neighbourhood as implementers. Thus, purely scientific research projects can arise in the neighbourhood and industrial research or projects from civil society can be implemented. Collaborative projects from the above-mentioned groups of actors are also welcome in this approach. It does not always have to be research projects: low-threshold approaches such as surveys or utilisation concepts are also conceivable.

Helleheide – Thinking ahead with Ideas in the Neighbourhood

To plan the organisation of a long-term operation of a Living Lab Helleheide, the partners in ENaQ considered the following central questions in advance:

- What concrete resources can we offer in Helleheide?
- In which domains or thematic areas would we like to locate follow-up projects?
- Where are there concrete points of contact?
- How can we ensure the involvement of the residents?

- How can the continuity of an innovation management and an advisory board be established and financed?
- How do we present this offer and the hoped-for use in a comprehensible way to third parties?

Since spring 2022, the partners in ENaQ have been offering a series of events to give interested stakeholders an initial overview of the possibilities for follow-up projects. Participants can find out about the future research environment in Helleheide and talk to project partners and like-minded people. In addition, the events are intended to serve as an opportunity space where new impulses and impetus can be gathered from those actors who could possibly offer their products and services in the neighbourhood in the future. In the future, there should be a continuation of regular, demand-based formats under the title “Thinking ahead with ideas in the neighbourhood”.

Consolidation of Smart City Innovation Management

As a living lab, Helleheide is geared towards the long term: ENaQ is the first project within the living lab and lays the foundation; further projects and ideas are to be prepared, developed and implemented within the framework of the laboratory. The prerequisite for this is an organisational structure that is sustainable in the long term and a sufficiently long-time horizon for the implementation of follow-up projects.

Part of this organisational structure should be a central contact point, which we call “Smart City Innovation Management”. It is the central point of contact for project submissions and technical enquiries from interested parties from business and science, and the contact for residents on the issues of the living lab. This means that it can be set up both in the sense of a classic office and as a physical contact point with premises for communal use in the Helleheide neighbourhood or in Oldenburg city centre.

The Smart City Innovation Management networks regional stakeholders from business and science for the exchange of expertise and the development of projects in the living lab. It is important to consider the city of Oldenburg and its surrounding area as a space for action and draw on existing networks. Public relations and communication are also in your hands. The Smart City Innovation Management supports the coordination of the Smart City Advisory Board and is thus an essential guarantor of success for the implementation of follow-up projects in Helleheide.

Establishment of a Smart City Advisory Board

The Smart City Advisory Board comprises regional institutions and personalities who are involved in the development and implementation of the overarching Smart City Vision of the City of Oldenburg. It will be initialised within the framework of the

ENaQ project. The central tasks of the Smart City Advisory Board include evaluating the work in the Helleheide neighbourhood regarding the active continuation of citizen participation, coordinating the work with other regional Smart City activities and ensuring the transferability of the knowledge gained and concepts developed in Helleheide to other neighbourhoods. Furthermore, an active exchange of knowledge and experience is to be organised within the framework of regular meetings of the Smart City Advisory Board.

With a view to the following activities in Helleheide, the Smart City Advisory Board can be given the task of advising on concrete ideas and sketches for projects and evaluating the results. In this way, it makes recommendations for possible Smart City implementations in the urban area. Furthermore, the Smart City Advisory Board itself acts as a “think tank” for the initialisation of new projects in the neighbourhood and within the framework of other regional Smart City activities. At the same time, it also has the task of reconciling the interests of stakeholders or other third parties if necessary.

1.6 Main Obstacles and Success Factors

Beside its research character, ENaQ is a practical implementation project that is exposed to numerous internal and external factors and changes that had an influence on the developments during the project. In the first four years of the project, for example, important framework conditions that influenced the choice of energy system in the neighbourhood changed rapidly and constantly.

1.6.1 Main Obstacles

The following main obstacles and developments should be mentioned:

– 2019: Changes in the framework conditions for housing development due to the increase in the land value, which led to a denser housing development as initially expected and planned.
– 2019/2021: Changes regarding the possibility of preserving some of the existing buildings with the decision to tear down most of the buildings due to a difficult exploration for explosive ordnance and the discovery of other contaminants within the buildings.
– 2019–2021: Uncertainties related to energy regulation in the area of operating the electric grid in the district as a Customer System (german: „Kundenanlage“[2]). The Customer System represented the prerequisite to offer local energy to the resi-

2 German legal wording: Öffentliches Verteilernetz, Geschlossenes Verteilnetz, Kundenanlage, Kundenanlage zur betrieblichen Eigenversorgung (EnWG § 110, 3 No. 24a, 24b, 29c).

dents of the neighbourhood at a low price and to profit from it at the same time. However, the requirements for a Customer System are not precisely defined in the legal framework (see Chapter 2). A significant consortium-generated knowledge gain emerged over the course of the project in this domain. Finally it has been decided that the operation of the electricity grid as a Customer System is not feasible for this district due to the combination of numerous framework conditions. The main and decisive factors were the need for connection of the local grid to the medium-voltage grid and the associated high and cost-intensive requirements for metering (necessity of costly registered power meters in the residentual units of the district). As an immediate consequence, the practical testing of the district aggregator business model had to be discarded.
- 2020–2022: Corona pandemic related delays in the exploration of explosive ordnance and more difficult public participation processes.
- 2021–2022: Distortions on the energy markets: 2021 has clearly shown that the energy market is an acutely risky market environment. Small and medium-sized companies had a hard time, which was reflected in the flood of insolvencies among smaller energy suppliers. Within the ENaQ project the distortions on the energy markets also led to the bankruptcy of one of the project partners.
- 2021–2022: Significant changes in housing subsidies: Reorganisation of KfW funding as of July 2021, stop of funding in January 2022, (partial) resumption of funding for renovation in February 2022, changed conditions for new houses in April 2022.

1.6.2 Main Success Factors

Besides the effects that interfered with the project, there were also factors that contributed significantly to the progress of the project. The following highlights a few of them:
- **Regular communication.** Since the content of research projects is off the status quo, it is helpful to communicate the perceptions on a regular basis. This helps to keep a shared and lasting vision. We have used the following formats for this:
  - Close cooperation of the subproject managers
  - Monthly meetings of the subprojects with status reports
  - Monthly internal newsletter
  - Semi-annual consortium meetings
  - Consortium-wide creative workshops on special topics on a voluntary basis
- **Appropriate tooling**. An appropriate tooling helped to save and transfer knowledge and to deal with staff changes. Further, during times of pandemic-related phases of remote work, collaboration and creativity tools helped to maintain productivity. We have used the following tools for this:
  - Video conference tool
  - Ticket system

  - Project-Wiki
  - ConceptBoard (Miro)
- **Diversity.** To keep the goal in mind, it is helpful to establish as diverse an opinion as possible. This includes the participation of external and internal stakeholders of the project. For example, workshops on deliverables with heterogeneous groups have created common understanding and uncovered misunderstandings.
- **Creativity.** The design of a project atmosphere has a far-reaching influence on the results. We have found that thinking outside-the-box is encouraged by creative workshop approaches. We have used the following formats for this:
  - Creating Persona Profiles
  - Design thinking/ visual thinking
  - Iterative workshops with heterogeneous and homogeneous groups
  - Interactive workshop formats
  - Co-creation approaches

  As an example, we would like to mention the development of a district energy system planning and learning board game as an example of a creative process where multiple project partners contributed to and that is now widely used for project dissemination activities. The development process has been published by Lanezki, Siemer and Wehkamp (2020).
- **Varieties of Responsibility.** We have found in the project that apart from the leads in work packages, other forms are very helpful. These include the support of personal motivation to create voluntary responsibility, or even formal forms, such as the development plan of an area.
- **Up-to-date-ness.** We could see that during the project, the regulatory, legal and economic environment changed constantly. Close monitoring of these areas is a regular and important consideration in design decisions for project content such as energy supply.

  An example is the changed registration procedure for micro/balcony PV systems and a targeted promotion by the city of Oldenburg. This led to the inclusion of such plants as a further component of the decentralised energy supply in the neighbourhood and as an active component in citizen participation process.

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Steffen Wehkamp, Lucas Schmeling, Sven Leonhardt

2 Regulatory and Legal Challenges for District Energy Systems in Practice and Research

Summary: In line with the objectives of the European Commission, local and sustainable energy systems are to be implemented. The energy supply sector is subject to strong regulation because of its critical and sensitive nature. Innovative ideas are often tested first in simulations and later in reality (living labs). In practice, there is a lack of clarity in the regulations and in the communication on how these goals are to be implemented. The objective of this paper is to explore how regulatory aspects can pose an uncertainty for the planning in this area. For this purpose, the current legal framework for local energy systems is examined using the example of a customer system. A qualitative potential analysis is carried out in terms of feasibility. A potential model could be presented, in which the regulatory layer limits the technical potential. It has been shown that regulation that is not clearly defined can represent uncertainty in the form of economic risk. If this uncertainty is too great, it limits the economic and thus the sustainable potential.

2.1 Motivation

The development of the energy transition in Germany so far is taking place away from urban areas. Part of the energy transition is to increase the share of renewable energy technologies. The largest share of renewable energies, are photovoltaic systems (PV), wind turbines on- and offshore. Project developers of wind farms and open field installations of PV and home PV installation owners benefited from the subsidy conditions.

Acknowledgments: The authors thank all the other ENaQ project partners for support, inspiration and fruitful discussions.

Funding: This research was funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Federal Ministry of Education and Research (BMBF) of Germany in the project ENaQ (project number 03SBE111).

Steffen Wehkamp, OFFIS e.V. – Institute for Computer Science, R&D Devision Energy, Escherweg 2, 26121 Oldenburg, e-mail: steffen.wehkamp@offis.de
Lucas Schmeling, Lintas Green Energy, Alter Stadthafen, 3b, 26122 Oldenburg, e-mail: l.schmeling@lintas-greenenergy.de
Sven Leonhardt, ubineum, Uhdestrasse 25, 08056 Zwickau, e-mail: sven.leonhardt@fh-zwickau.de

https://doi.org/10.1515/9783110777567-002

It was found that stakeholder acceptance is a major factor in the success of such projects. Acceptance can often be achieved through social, economic and physical participation. Thus, in the first step, the construction of wind turbines and PV could be achieved through financial support (Agora 2020).

To date, many PV installations, such as rooftop PV, in rural areas have been obtained through incentives. The next target for subsidies is the urban area, in that the previous support mechanisms were less effective. In cities, the energy demand density is very high and the potential for renewable energies is relatively low. Thus, the city is a critical area in need of energy supply on the way to climate neutrality.

The support of renewable energies, also in urban areas, initially took place via fixed feed-in tariffs, then direct marketing and now also to some extent via tenant electricity. It was also possible to lease roof areas to project developers, such as energy cooperatives. The system operator of a tenant electricity building was supported, while the low-cost provision to tenants in the same building was obligatory.

2.1.1 Local Energy Districts

To include the urban area more in the energy transition strategy, the idea of efficient local supply was developed, in which several stakeholders act together as an energy community. The European Commission introduced the term "Citizen Energy Community" (CEC) in the Clean Energy Package and "Renewable Energy Community" (RES, EU2019). The Clean Energy Package contains several Directives. These Directives represent a request from the European Union to integrate the contents into national law.[1] Within this CEC, for example, the trading of electricity surpluses between neighbors, as well as the distribution of heat via local heating grids should take place. Whereas the REC is not limited to a local area, but in the choice of technologies to renewables.[2]

Similar ideas were already developed and implemented in the Vauban neighborhood in 1993. In this quarter, a low-car traffic concept was followed, and a decentralized energy supply was built via a wood and gas combined heat and power plant (CHP) and PV. In German law, the legal form of the cooperative[3] was used for this purpose. In this case, the operation of the plants was managed by the cooperative, and there was no direct energy trade between residents (Vauban 2022).

1 Regarding CES, the Electricity Directive 14/06/2019 – Directive (EU) 2019/944 includes in Article 16 the requirements on how to form a regulatory framework for CES.

2 This is already requested by the European Commission in the Clean Energy Package. See Renewable Energy Communities and Citizen Energy Communities. (Renewable energy: 21/12/2018 – Directive (EU) 2018/2001, Governance of the energy union: 21/12/2018 – Regulation (EU) 2018/1999, Electricity directive: 14/06/2019 – Directive (EU) 2019/944). Available at: https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en#electricity-market-design.

3 German: *„Genossenschaft."*

The core of the idea and such district approaches lies in energy efficiency. The aim is to reduce energy consumption as much as possible and to supply the remaining consumption as efficiently as possible. Local supply, e.g. by PV, can save transport and the associated losses. But it can also make sense to accept pipeline losses, e.g. in local heating grids, to supply heat with highly efficient CHP.

This article focuses mainly on the power sector. However, since the sectors are strongly interrelated in the field of energy system planning, energy is often referred to generically here. The form of energy or the energy carrier (electricity, heat, gas) is irrelevant when addressing some issues and is therefore not always discussed in detail.

2.1.2 Planning Phase of Districts

When planning such districts, the priority is to examine the potential of the project. This includes, above all, (1) the coordination of the partners involved (building society, local energy supplier, potential residents, local grid operator), (2) the development plan[4] and (3) the choice of an energy supply concept for the district.

In step (1), a common goal is worked out. Here, a vision is formulated at a relatively high level of abstraction. Step (2) deals with concrete conditions for the development of the district. This includes, for example, the parking space ratio for cars and the possibility or obligation to build energy systems on the roofs.[5] In step (3), the design of the energy supply must be determined. For this purpose, energy consumption is forecasted and a possible energy supply is determined. The choice of connection to the power grid is an important parameter of this decision. The owner of the property can decide whether to make a connection request to the (gas and electricity) grid operator, which voltage level to choose depending on the local energy system, or even whether a self-sufficient grid is planned.

Based on the jointly developed objectives, the various concepts of potential can first be defined (see Figure 2.1).

The following potential terms were defined based on VDI (2019) and Hadlak (2020):

- Theoretical potential:
  - Limits of physics.
- Technical potential:
  - Limits of current research and development.
- Practical potential:
  - Limits of regulation, administration and law.

4 German: *„Bebauungsplan.“*

5 In development plans, specifications can already be made for various things, such as parking ratios and roof use. The context here is the energetic use. Number of charging columns, roof area that can be used for energy, etc.

- Sustainable achievable potential
  - Intersection of economic, environmental and social potential that can be sustained. Each has its limitations. The smallest intersection is the one that is sustainably achievable for all dimensions.
    - Economical potential
    - Ecological potential
    - Social potential

While investigating the practical potential, we encountered the regulatory framework of the supply grid for such a district. This will be discussed in the following chapter.

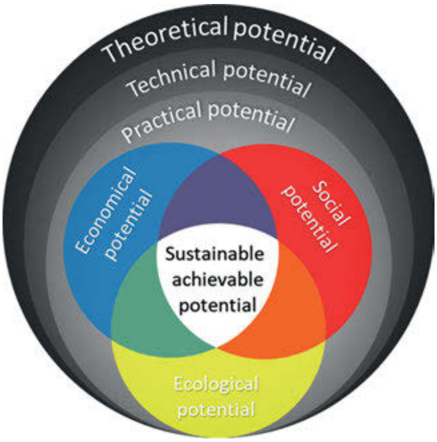

Figure 2.1: Potential terms in the context of energy flexibility.
(Source: Bauer 2016, Dufter 2017, Hadlak 2020, Ausfelder 2020, VDI-Richtlinie VDI 5207)

2.2 History and Overview of Power Supply Grids

The energy industry is a highly regulated area by design. This is due to the precarious nature of the energy system, as is made clear by § 1 of the German Energy Industry Act (EnWG). The following list is intended to briefly illustrate the expert knowledge required to operate in the regulated environment of the energy industry.

Thus, in addition to the EnWG, the regulatory areas are divided into other more specific legal texts such as EEG for renewable energies, KWKG for combined heat and power, StromNZV for access to electricity grids, EnEV for energy conservation, StromGVV for basic electricity supply, GasGVV for basic gas supply, StromNEV for electricity grid fees, GasNEV for gas grid fees, StromStG for electricity tax or EnVKG for energy consumption labeling.

For investments, it is necessary to have legal and regulatory security for the respective project. Various risks are mapped via a risk interest rate to secure the project. Utilizing an example, it shall be shown here that broad detailed knowledge is required to be able to assess the regulatory environment with certainty. Similar terms may be defined differently in different legal texts.

The term end consumer is defined in the legal texts EnWG (§ 3 No. 25), EEG (§ 3 No. 33) and KWKG (§ 2 No. 17). The latter two definitions are identical:

> *any natural or legal person who consumes electricity.*[6]

The definition of the EnWG deviates from this since it already concerns the purchase of energy for the own consumption. This means that final consumption only applies to purchased energy, but not to self-generated and consumed energy if one follows the EnWG.[7, 8] In addition to the multitude of regulations, which must be known to determine the legal certainty, there are also changes in the regulations, which are intended to serve the path to the desired energy system. But even such changes are initially associated with uncertainties. In the case of district power supply, the construction of so-called customer systems[9] has become established. The customer system represents a special non-regulated form of the power grid. This form of grid will be explained in the following. For this purpose, the various forms of power grids in the regulatory system will be discussed, and the associated practice will be explained.

2.2.1 Public Supply Grids

Public supply grids are basically available to supply any end user. It is legally defined in EnWG § 3 No. 17. Due to the public nature of these grids, there are various regulatory requirements for this form of grid. These include:

1. Incentive regulation,[10]
2. Regulation of grid operation (such as: general connection obligation),[11]

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6 German original: *„jede natürliche oder juristische Person, die Strom verbraucht."*

7 German original: *„Natürliche oder juristische Personen, die Energie für den eigenen Verbrauch kaufen; auch der Strombezug der Ladepunkte für Elektromobile und der Strombezug für Landstromanlagen steht dem Letztverbrauch im Sinne dieses Gesetzes und den auf Grund dieses Gesetzes erlassenen Verordnungen gleich,."*

8 Further examples are the terms grid operator (§ 3 No. 36 EEG, § 2 No. 21 KWKG) or operator of: electricity distribution grids, gas distribution grids, energy supply grids (electricity supply grids or gas supply grids), long-distance transmission grids, transmission grids, transmission grids with control area responsibility, hydrogen grids (§ 3 No. 2–5, 7–8, 10–10b, 16 EnWG).

9 German: *„Kundenanlage"*, EnWG § 3 Nr. 24a. & 24b.

10 EnWG § 21a Regulatory requirements for incentives for efficient service provision; German original: EnWG § 21a *„Regulierungsvorgaben für Anreize für eine effiziente Leistungserbringung"*. Further: Ordinance on Incentive Regulation of Energy Supply Grids (Incentive Regulation Ordinance); German originial: *„Verordnung über die Anreizregulierung der Energieversorgungsnetze (Anreizregulierungsverordnung – ARegV)."*

11 EnWG Part 3 §§ 11–35 Regulation of grid operation; German original: EnWG *„Teil 3 §§ 11–35 Regulierung des Netzbetriebs."*

3. Unbundling of grid and supply,[12]
4. Right to levy grid charges,[13]
5. Compliance with the standards for business processes for the supply of electricity to customers.[14]

Transmission grid. The transmission grid includes the transmission of electricity over long distances, federal states and also countries. The voltage level is ≥ 220 kilovolts and is called high and extra high voltage. Large power plants and industrial electricity consumers are connected to the transmission grid. It is legally defined in EnWG § 3 Nr. 2, 10, 10a.

Distribution grid. The distribution grid includes the transmission of electricity within regional zones, counties and cities. The voltage level is ≥ 400 volts and is called medium and low voltage. Medium power plants, industry, commerce and households are connected to the distribution grid. It is legally defined in EnWG § 3 Nr. 3.

2.2.2 Grids for Specific End Consumers

Local distribution grid. This distribution grid is separated from the grid level above by the concession area. It is legally defined in EnWG § 3 Nr. 29c.

Closed distribution grid. This special type is not connected to the public supply grid and is considered an island grid. It is often used for industrial and commercial areas. It is legally defined in EnWG § 110. This form of grid requires an approval request. The state regulatory authorities or Ruling Chamber 8 are responsible for the approval (Fietze 2019). Now it is necessary to meet the regulatory obligations 1 fully and 2 for the most part. However, large parts of 3. (unbundling) and 5. (business process standards) remain unregulated (DIHK 2017).

Object grid (Areal grid, Factory grid). This form of grid served as an exception to the regulated grid area. Thus, the above-mentioned regulatory provisions did not apply in this grid. Object grids are separate from the regulatory system and are self-managed. It was intended to decouple grids for linked operational supply from the

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12 EnWG Part 2 §§ 6–10e – Unbundling; German originial: EnWG „*Teil 2 §§ 6–10e – Entflechtung*."

13 Former: EnWG § 92 Fee, Now: Ordinance on Charges for Access to Electricity Supply Grids (Electricity Grid Charges Ordinance); German original: „Verordnung über die Entgelte für den Zugang zu Elektrizitätsversorgungsnetzen (Stromnetzentgeltverordnung – StromNEV)."

14 Business Processes for the Supply of Electricity to Customers – in accordance with Ruling RC6-19-218 of 11.12.2019; German original: „Geschäftsprozesse zur Kundenbelieferung mit Elektrizität (GPKE) – gemäß Beschluss BK6-19-218 vom 11.12.2019."

public supply grid. It was legally defined in EnWG § 110 until 04.08.2011. The reason for the change was a decision on illegality under European law (Fietze 2019).[15]

Customer systems. This form of the grid has been in force since 04.08.2011. It represents the new form of the unregulated grid area and thus replaces the former object grid. It is legaly defined in EnWG § No. 24a. These customer systems are grids for small local residential areas.

Customer systems for company self-supply. It is legaly defined in EnWG § 3 Nr. 24b. These customer systems for company self-supply are grids for small local industrial and commercial areas.

2.2.3 Distinguishing between Power Line and Grids

Direct Line. A line between a single power generation facility and a single point of energy consumption. It is legally defined in EnWG § 3 Nr. 12.

2.3 Legal Uncertainty in Practice of District Energy Systems

Grids in districts, quarters, neighborhoods and between individual residential and/or commercial buildings were operated as customer systems (formerly object grids). These grids are outside the regulation of the EnWG. Regulation at this point refers to the points mentioned in 21.2.1. There are still requirements of a regulatory nature, such as the non-discriminatory choice of electricity suppliers within the customer system.

The term customer system was explained in the previous subchapter. At this point, the advantages and disadvantages of the customer system are intentionally not discussed. This is often accompanied by the question of whether they are justified or whether this is a tax-saving model. This is part of the support policy debate. This particular controversy of the customer system is not intended to be part of this article. Rather, this article presents the circumstance of how uncertainty about the regulatory implementation of local energy systems can have an effect for the decision making process.

In practice, this new regulation of customer systems led to increased legal uncertainty. This was mainly due to the lack of a possibility to have the status of one's system confirmed. Thus, unregulated grids were built and operated according to given non-regulation without confirmation whether this was legal. There was no verification or confirmation mechanism in place (BBH 2011). Thus, it is possible that the oper-

15 Infringement of Art. 20 of the Electricity Directive of 2003, identical to Art. 32 EltRL 2009.

ators of such plants will be sued due to the lack of regulation and, in the event of a corresponding ruling, their operation will be prohibited. The amendment of the EnWg in August 2011 for the first time specified facts for the delimitation of customer systems. However, these were only descriptive and not nominal (BBH 2012).

2.3.1 Rulings as Guidelines

From this circumstance, the practice developed that rulings against the status of a customer system were referred to, to be able to assess one's legal uniqueness. For this purpose, the nominal facts that contradicted the status of a customer system were taken from the reasons given in the court rulings.

This is to be illustrated by the example of residential customer systems according to EnWG § 3 Nr. 24a. The four criteria for a customer system are:
1. Territorial unit,
2. Connection to an Energy Supply Grid or to a generation facility,
3. Insignificance for competition and
4. Non-discriminatory and free use for everyone.

2.3.1.1 Territorial Unit

03.04.2017: In the Ruling Chamber 6, in the ruling RC6-15-166, the status of a customer system was withdrawn, because the territorial unit is not given, if the energetic units are separated by a four-lane road.

12.11.2019: The Federal Court (EnVR 66/18) confirms the status of a customer system due to its physical coherence.

12.11.2019: The Federal Court (EnVR 65/18) withdraws the status of a customer system due to its lack of physical coherence. The external perception is of decisive importance here.

2.3.1.2 Connection to an Energy Supply Grid or a Generation Facility

To date, there is no court ruling based on this criterion.

2.3.1.3 Insignificance for Competition

This characteristic can be further subdivided into:

1. Number of connected end consumers
27.07.2017: In the Ruling Chamber 6, in the ruling RC6-16-279, the status of a customer system was confirmed, because the insignificance for competition is given. The justification referred to the number of end users, which was 20 row houses.

03.04.2017: In the Ruling Chamber 6, in the ruling RC6-15-166, the status of a customer system was withdrawn, because the insignificance for competition is not given. The justification referred to the number of end users, which was 457 and 515 households.

08.03.2018: The Frankfurt Higher Regional Court (Case No. 11 W 40/16 (Kart)) questions the status of a customer system. In its reasoning, the number of 397 households was considered to be contrary to the status of a customer system.

12.11.2019: In the ruling EnVR 65/18 the Federal Court declines the status of customer systems if *„several hundred end consumers are connected"*. This judgment should be evaluated in the context of the other nominal quantified factors since it was made with an AND-conjunction. This ruling confirms the ruling of Ruling Chamber 6 with the case from RC6-15-166.

26.02.2020 The Düsseldorf Higher Regional Court (Case No. VI-3 Kart 729/19) confirmed the status of a customer system with 200 households.

25.01.2022: The Federal Court (EnVR 20/18) confirms the withdrawal of the customer system status from case 11 W 40/16 (Kart). A further trend-setting judgment is expected.

2. Geographical area
03.04.2017: In the Ruling Chamber 6, in the ruling RC6-15-166, the status of a customer system was withdrawn, because the insignificance for competition is not given. The justification referred to the geographical area of 44,631 m^2 (13 plots and 22 residential buildings) and 53,323 m^2 (17 plots and 25 residential buildings).

12.11.2019: In the ruling EnVR 65/18 the Federal Court declines the status of customer system if *„the plant supplies an area of well over 10,000 m^2 and several buildings are connected"*. The exceeding amount, in this case, was 44,631 m^2 and 53,000 m^2 as well as 22 and 30 buildings. This judgment should be evaluated in the context of the other nominal quantified factors since it was made with an AND conjunction. This ruling confirms the ruling of Ruling Chamber 6 with the case from RC6-15-166.

3. Quantity of transmitted energy
03.04.2017: In the Ruling Chamber 6, in the ruling RC6-15-166, the status of a customer systems was withdrawn, because the insignificance for competition is not given. The justification referred to the quantity of transmitted energy, which was 1,005 MWh/a and 1,133 MWh/a.

08.03.2018: The Frankfurt Higher Regional Court (Case No. 11 W 40/16 (Kart)) questions the status of a customer system. The amount of transmitted energy is between 1,000 and 1,200 MWh/a.

26.02.2020 The Düsseldorf Higher Regional Court (Case No. VI-3 Kart 729/19) confirmed the status of a customer system with a quantity of 450 MWh/a transmitted energy.

12.11.2019: In the ruling EnVR 65/18 the Federal Court declines the status of customer systems if *„the annual amount of energy transmitted is expected to significantly exceed 1,000 MWh“*. The exceeding amount, in this case, was 1.483 MWh/a and 1.672 MWh/a. This judgment should be evaluated in the context of the other nominal quantified factors since it was made with an AND-conjunction. This ruling confirms the ruling of Ruling Chamber 6 with the case from RC6-15-166.

25.01.2022: The Federal Court (EnVR 20/18) confirms the withdrawal of the customer system status from case 11 W 40/16 (Kart). The amount of transmitted energy is between 1,000 and 1,200 MWh/a. A further trend-setting judgment is expected.

4. Other characteristics
To date, there is no court ruling based on this criterion.

2.3.1.4 Non-discriminatory and Free Use for Everyone

18.10.2011: Federal court (EnVR 68/10) decides that consumption-based costs for the use of the customer systems lead to the withdrawal of the status of a customer system. An increased electricity price within the customer systems also indicates hidden consumption-based costs.

2.3.1.5 Interim Conclusion

The opposing parties in customer system projects were often the local distribution system operators, housing companies or smaller energy suppliers. Project developers or operators of such systems were able to use the rulings to identify boundaries for the individual facts of customer systems. However, there were large gray areas, such as the number of end users between 20 and 397 households (as of 08.03.2018).[16] In addition, some factual characteristics are less nominal, such as the territorial unit criterion. Other factors have not yet been used at all to make a judgment and remain open to date.

16 Current grey area is between 200 and 397 households as of 26.02.2020.

Based on these examples, it can be seen that the ruling practice in the courts is characterized by uncertainty.

2.3.2 Local Electricity Trading via District Aggregator

Any sale of electricity to end customers generates the status of an energy supply company. The high requirements for energy supply companies[17] make local trading by private individuals and non-specialized trade extremely difficult. Previous studies have presented the business model of the aggregator or, in this case, the neighborhood aggregator (Nemanja 2021). The regulatory framework with the constellation of an aggregator in a customer system is presented below. This list does not claim to be complete.

In principle, the structure of actors in an energy neighbourhood in a customer system is similar to that found in the German energy industry as a whole. The only difference is the size of the area supplied. Associated with this is a new market role that controls the energy flows in the neighborhood. This role is assumed by the neighborhood aggregator. Especially for this actor and its interaction with the other actors, new situations arise that have to be investigated from a legal and regulatory point of view.

The case of self-consumption with the sale of the surplus quantities in terms of the feed-in tariff corresponds to the currently established case and does not require further legal examination. Newly added at the district level is the possibility to deliver the electricity to the aggregator in its role as a local direct marketer (see § 3 Nr. 16 EEG / § 4 KWKG) or energy flow coordinator. There is an energy purchase agreement between these actors, which regulates the scope and remuneration of the electricity supply.

Due to the connection of the customer system to the medium-voltage network of the grid operator, registered power measurement meters (RPM) are used to record electricity consumption when a final consumer is supplied by external energy supply companies. These consumers are then subtracted from the reference quantity of the grid access meter, thus virtually removing these customers from the customer system.

17 German: *„Elektrizitätsversorgungsunternehmen“* following § 3 Nr. 20 EEG (Renewable Energy Sources Act).

2.3.2.1 Customer System Operators

The customer system in the neighborhood is operated either by the aggregator itself or by an external service provider on behalf of the aggregator. The costs incurred for this are passed on to the end consumer.

Due to the legal uncertainty of the status of a customer system, the withdrawal of the status must be taken into account. In this case, the distribution system operator is generally not obliged to return the existing grid to the public grid. Each subscriber may have to submit a new connection request to the grid operator. This may entail new connection costs for the subscriber. It is possible to agree with the distribution system operator to construct and operate the customer system in accordance with the standards of the higher-level grid. In the event of a reversal, the grid operator could therefore take over the customer system at its asset value and convert it into a classic public supply grid.

In the context of Chapter 2.3.1.4, important for refinancing is, according to § 3 No. 24a EnWG, that this is available to the end consumers free of charge. The legislator's main aim here is to prevent the choice of energy supplier from determining who participates in the financing and to what extent. In this logic, it is therefore important that refinancing is not carried out together with the neighborhood electricity product and certainly not dependent on consumption, but rather, for example, via the property owner or a flat rate for network use to be paid by all tenants. Since both tenants and property owners benefit from favorable electricity prices, this can be justified to a certain extent.

2.3.2.2 Metering Concept

The metering of electricity flows in the neighborhood is carried out by smart metering systems, which are installed and managed by a metering service provider. Since the Metering Point Operation Act (MsBG) does not apply within the customer system, the installation of the metering infrastructure and the choice of the scope of functions is the responsibility of the customer system operator.

The metrological equipment must comply with the provisions of the Measurement and Calibration Act and also with the requirements of § 21e (2–4) of the EnWG.

The operator of the customer system is responsible for the selection and installation of the metering systems within the customer system. The public grid operator is responsible for the metering concept at the grid connection point of the customer system, as well as the measurements at the customers supplied by third parties.

In accordance with § 20 Nr. 1d (1) EnWG, the operator of the Energy Supply Grid to which the customer system is connected, i.e. usually the distribution grid operator, is responsible for the sub-meters relevant for balancing. This operator assigns a corresponding market and metering location[18] and thus includes this end consumer in the usual processes of market communication, which is not necessary for internally supplied end consumers. The basic metering point operator (bMPO)[19] then installs the metering infrastructure that is now required. Of course, the end consumer is also free to choose a competitive metering point operator (cMPO)[20]. If the customer system is connected to the medium-voltage grid, it must necessarily be RPM. An externally direct-marketed plant is basically subject to the Metering Point Operation Act (MsbG). Consequently, the plant operator is responsible for the metering concepts in coordination with the responsible distribution grid operator. The hardware is then provided by the basic metering point operator, but the operator can also turn to a third-party metering point operator to install and deploy the metering infrastructure for him.

In the ruling RC6-06-009, it was stipulated in 2006 that the metering concept must enable the allocation of meters within the customer system for end customers. It must be possible to automate the handling of business processes (GPKE38).[21] According to § 20 (1d) EnWG, the operator of the higher-level network must provide a) the meter for the customer system and b) all sub-meters within the customer system that are relevant for accounting.

2.3.2.3 End Consumer

The end user in the district generally has two options for covering his electricity demand, apart from self-consumption of self-generated electricity:

1. purchase from the aggregator,
2. purchase from an external energy supply company.

The possibility of external supply must be guaranteed according to § 3 Nr. 24a EnWG. This case corresponds to the current normal case and does not represent a special case of the quarter-internal power supply.

In case an end consumer wants to switch his electricity supply between options 1. and 2., the same legal principles according to the EnWG apply. However, since the grid operator generally has no knowledge of the customers in the customer system, it is the responsibility of the customer system operator to order a market location for the customer wishing to switch to the grid operator. A normal change of grid supplier is then handled via this market location.

18 German: *„Markt- und Messlokation (MaLo/MeLo).“*
19 German: *„Grundzuständiger Messstellenbetreiber (gMSB).“*
20 German: *„Wettbewerblicher Messstellenbetreiber (wMSB).“*
21 Last change in RC6-11-150 from 28.10.2011.

2.3.2.4 Prosumer

Private individuals will rarely deal intensively with the legal situation of their power supply themselves. Here, there is a need for advice and handling of certain processes by a service provider. Therefore, no private individuals may be plant operators in a neighborhood.

2.3.2.5 Feed-in Tariff

The remuneration of energy generation plants within the customer plant depends on the operator and operator model. For electricity from PV plants, the aggregator receives the market premium from the distribution grid operator according to § 19 Nr. 1 1(1) EEG / feed-in tariff according to § 19 Nr. 1 (2) EEG, for electricity from CHP it receives the surcharge for grid-fed or § 7 Nr. 3 KWKG the surcharge for non-grid-fed CHP electricity according to § 7 Nr. 1 KWKG. These revenues refinance the compensation paid to the plant operator. The difference between the remuneration paid and the market premium/KWKG surcharge must be made up by marketing the electricity on internal or external markets.

2.3.2.6 Deconstruction of the Customer System

In the event of a successful lawsuit against the status of the customer system, the operator of the customer system is responsible for the costs of deconstruction. In addition, there are often various costs for the legal proceedings. No statement can be made here about further costs, e.g. on the basis of claims for damages.[22]

2.4 Legal Uncertainty in Research Projects

Within the research of living labs, a technical focus, practical experience and knowledge of current adjudication practice are required. However, in our experience, the integration of legal expertise into a project consortium is difficult to *implement* and *involves* high personnel costs. It can be done either via subcontracting or via integration of expertise as a funded partner. The latter has the advantage of being able to clarify legal issues promptly at any time without additional engagement.

22 German: *„Schadensersatz-Ansprüche."*

The sister project "Zwickau energy transition demonstration" (ZED)[23] had such a partner, a large business and legal auditing company, in the consortium of an already evaluated project outline. Here, of course, the focus was on the topics of the basic regulatory framework and how it can be improved. Overall, the partner was thus planned as a cross-sectional task almost across all work packages with a not insignificant funding amount in the seven-digit range. During the project submission phase, the budget for such expertise was greatly reduced. This was justified by the ministry and the funding agency because answering such fundamental regulatory questions is not part of this research initiative. Rather, it was the task of accompanying research or higher-level research by institutions commissioned by the federal government to clarify these issues. Instead, the funding agency took on targeted issues by engaging a legal report (BMWK 2020).

This means that research projects like those of this research initiative and the consortia contributing here are not able to make basic research and general statements on these topics. In the course of these projects, we have made the experience that the inclusion of legal expertise is necessary for such investigations. However, in the area of innovative research, one encounters the limits of regulation, which can also be referred to as gray zones. Such existing uncertainties in the ruling practice cannot be compensated for by the most competent partner. Based on the experience gained in the projects, we recommend that the topic of legal certainty be given greater prominence in practical projects and, if necessary, that funding be provided for energy law issues within an appropriate framework.

The ministry has recognized this fact and is calling for clear regulatory insight interest for future living labs. Testing different regulatory approaches in living labs is referred to as regulatory learning. It is intended to give research projects an active role in shaping future legislation. This is partly made possible by exception clauses, as already tested in SINTEG projects (BMWK 2021).

2.5 Conclusion

Achieving the goals of the national energy transition and the international Paris Agreement will require an immense political commitment to the necessary measures. Researchers, climate associations and often governments themselves call for the implementation of innovative (decentralized) energy concepts. It could be shown that certain forms of sustainable decentralized (local) energy supply systems are not an option. This is due to the fact that unclear regulation prevents certain forms of sustainable decentralized (local) energy supply systems through regulatory uncertainty, which has the effect of an economic risk.

23 German: *„Zwickauer Energiewende demonstrieren (ZED).“*

The practice has recognized that the government's goals and current case law are not consistent with each other. The regulation currently restricts the implementation of above mentioned sustainable innovative supply concepts. Case law continues to accord the customer system the exceptional character (Richter 2020). Thus, there is a lack of understanding of how the government intends to implement its own goal of decentralized energy supply. There is a lack of a communicated concrete concept. This is accompanied by two demands: 1) creation of appropriate regulation to own objectives, 2) elimination of uncertainties within regulation. This is also reflected in the criticism of the implementation of the Clean Energy Package directives, which include the introduction of the legal forms "Citizen Energy Community" (CEC) and "Renewable Energy Community" (REC).

In research, too, the regulation makes it difficult to test innovative supply concepts. Regulation in living labs is intended to protect participants and is thus a reasonable claim. Regulation must ensure a safe and just form of care, and this applies to research as well. The regulatory framework is often created for the status quo and thus hinders the exploration of innovative concepts in living labs. The claim that research is open to results can thus only be understood within the restrictive frame of the regulatory framework.

In this paper, the example of local power supply systems was used to show the limitation of technical potential by regulation. Furthermore, it has been shown that regulation that is not clearly defined can represent uncertainty in the form of an economic risk. If this uncertainty is too great, it limits the economic and thus the sustainable potential. Thus, the statement of the present study is only qualitative. For a quantitative statement, the factor of the reduction of the potential through regulation would have to be determined. For this purpose, the climate reports of the IPCC can be consulted. These show that the technical potential is sufficient to avert the climate crisis. It also shows that regulatory adaptation can contribute very strongly to mitigating the climate crisis (IPCC 2022).

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Peter Klement, Patrik Schönfeldt, Lucas Schmeling

3 Multi-Objective Design Optimisation of District Energy Supply – The Influence of Different Domestic Hot Water Concepts

Summary: The supply of districts with electricity and heat can be designed in a variety of ways. This concerns the technical building equipment on the one hand and the sizing and operational management of energy-generating and energy-storing systems on the other hand. We used the "Model Template for Residential Energy Supply Systems" (MTRESS) to simulate and optimise supply concepts with respect to energy costs, CO_2 emissions, and own-consumption using the example of the Helleheide neighbourhood. In the study, district heating network supply concepts based on 80 °C for direct domestic hot water supply, 40 °C with reheating for water treatment and legionella prevention and 40 °C without reheating but on-demand heat exchangers or ultra-filtration are compared. We find that most optimal solutions strongly integrate the heat supply with the electricity sector, with solar thermal supply being an exception to this general trend. Furthermore, operation and sizing of energy supply systems can have a bigger impact on both emissions and total costs than the actual choice of the technologies.

Funding: This research was funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Federal Ministry of Education and Research (BMBF) of Germany in the project ENaQ (project number 03SBE111)

Acknowledgments: The authors thank all the other ENaQ project partners for support, inspiration and fruitful discussions.

The authors would like to thank in particular the following partners for the preparation of the catalogue of key performance indicators: DWG (overall coordination, coordination energy system), OFFIS (coordination digital platform, coordination project in general), BTC, Embeteco, DLR, City of Oldenburg (coordination mobility), University of Oldenburg (coordination participation), KEHAG, EWE NETZ, ARSU, University of Vechta, NPP, GSG, ESP, SCHULZ, Quantumfrog, VWG.

The authors acknowledge Lena Vorspel for providing the heat demand time series.

Peter Klement, Deutsches Zentrum für Luft und Raumfahrt e.V., Institut für Vernetzte Energiesysteme, Carl-von-Ossietzky-Straße 15, 26129 Oldenburg, e-mail: peter.klement@dlr.de
Patrik Schönfeldt, Deutsches Zentrum für Luft und Raumfahrt e.V., Institut für Vernetzte Energiesysteme, Carl-von-Ossietzky-Straße 15, 26129 Oldenburg, e-mail: patrik.schönfeldt@dlr.de
Lucas Schmeling, Lintas Green Energy, Alter Stadthafen 3b, 26122 Oldenburg, e-mail: l.schmeling@lintas-greenenergy.de

https://doi.org/10.1515/9783110777567-003

Abbreviations

CHP	combined heat and power plant
COP	coefficient of performance
DHI	diffuse horizontal irradiance
DHW	domestic hot water
DNI	direct normal irradiance
ENaQ	Energetic Neighbourhood Quarter (German: Energetisches Nachbarschafts Quartier)
GT	geothermal
GHG	green house gas
HP	heat pump
KPI	key performance indicator
PV	photovoltaics
P2H	power to heat
SH	space heating
ST	solar thermal
WT	wind turbine

3.1 Introduction

Nowadays, energy supply systems not only have to provide energy, but energy must be provided at the lowest possible cost with minimal emissions. This results in the requirement that energy systems must be optimized with respect to several criteria. If these requirements cannot be fulfilled optimally at the same time, solution spaces arise, e.g., in the form of Pareto fronts, where the solution cannot be improved with respect to one criterion without at least one other criterion deteriorating.

For the energy supply, different technologies with different dimensions and in possible different combinations are usually available as options. Simulations of individual supply solutions usually involve a lot of effort. Therefore, the decision which technology combination in which dimensioning is to be used is usually made via simulation and comparison of individual scenarios. An optimization over many technologies and designs is therefore rarely carried out. Usually, only the costs for the energy supply are decisive. The avoidance of emissions follows in a downstream consideration when solutions with similar costs are compared. The aim of this paper is to present a concept in which energy system proposals are developed that are based on many technologies and in which the comparability of solutions with respect to various criteria is clearly visible.

Since the percentage of energy required for the provision of domestic hot water (DHW) in residential buildings continues to rise in line with the insulation standard (Zeisberger 2017), various supply concepts are currently under investigation (Energiewendebauen 2022).[1] From an energy point of view, there is always the desire to bring the supply temperatures as close as possible to the user temperatures to have to add as little cold water as possible. This increases the possibilities to supply DHW from renewable energy in an energy-efficient way. On the other hand, according to § 4 of the Drinking Water Ordinance,[2] it is a legal requirement in Germany how the quality and health safety of DHW must be ensured, e.g. with regard to legionella. Usually, this is ensured at the expense of energy efficiency by having to provide possible tap temperatures of minimum 60 °C at least for centralised DHW supply (DIN 1988–200:2012-05). The discussion about future possibilities to supply DHW is currently ongoing and being researched. Therefore, we would like to demonstrate our methodology by comparing conceivable concepts. There are various options to secure the quality of DHW especially with respect to legionella. An overview can be found in (Yang/ Li/Svendsen 2016). Here, we consider three options of DHW supply for demonstrating our concept:

S. 1	with flow temperatures at 80 °C,
S. 2	with flow temperatures at 40 °C, with legionella protection via on-demand heat exchangers or ultra-filtration.
S. 3	with flow temperatures at 40 °C with electrical reheating by flat for legionella protection.

One (S. 1) is heat supply well above 60 °C. To safely maintain this level at any place of the DHW plumbing system, we aim for a design flow temperature of 80 °C at the heating central. Alternatively, the temperature of the heat grid can be reduced to a level sufficient for space heating. We assume constant 40 °C at the heating central. As legionella population grows at that level, DHW cannot be stored. Instead, it is either heated on demand using heat exchangers (40 °C for both space heating (SH) and DHW, S. 2) or heated further using electric heating (DHW supply at 60 °C, S. 3), which according to (Völker/Kistemann 2015) is the minimum for safe hot drinking water storage. To model latter concept, the heat demand for DHW is reduced but electricity demand is added. Similar concepts for reduced heat network temperature have been investigated by (Toffanin/Curti/Barbato 2021). However, they rely on a micro booster heat pump instead of an electric boiler.

The three concepts were not made available for free optimization by the underlying technology selection because the decision is probably made because of considerations not part of the optimisation (i.e. legal concerns). Further, there is no inherent order in the choice of DHW supply solutions: While a pure choice of the temperature level would offer a common scale, so the decision about DHW solutions is of binary nature, leading to distinct optimisation problems anyway.

1 Research Project: EnOB: ULTRA-F – Ultrafiltration als Element der Energieeffizienz in der Trinkwasserhygiene, FKZ 03ET1617.

2 Verordnung über die Qualität von Wasser für den menschlichen Gebrauch (Trinkwasserverordnung – TrinkwV).

The methodology is explained in 3.2, whereas boundary conditions for the simulations are described in 3.3. The input data are presented at 3.4 and the results are shown in 3.5. A summary is given in 3.6.

3.2 Methodology

3.2.1 Goals and indicators

The basic concept of targeting and therefore deciding on a common objective between stakeholders was described by (Schmeling/Schönfeldt/Klement et al. 2020) from the Energetic Neighborhood Quarter (German: Energetisches Nachbarschafts Quartier, ENaQ) point of view. Specifically, the project partners, consisting of a company operating as a housing association, a university focusing on participation, a research institute dealing with renewable energy concepts, the local municipality, and companies from the energy and IT sectors, participated in the process. The involved persons took over different point of views as described by (Schmeling/Schönfeldt/Klement et al. 2020). The result is a catalogue of indicators, which can measure the effects of the ENaQ project, within the physical infrastructure, the participation process, the digital platform, and the project itself. The indicators chosen for the physical infrastructure focus on the energy system and the mobility. Due to the lack of partners who could directly and actively contribute to mobility solutions, sector-integrated energy concepts that include mobility had to be neglected. This article therefore focuses on the electricity and heat supply of a residential neighbourhood in the context of a sector integrating approach. The main goals therefore are:

- low greenhouse gas emissions,
- low costs,
- low exergy losses,
- high share of renewable energy,
- enabling of sector integration,
- high own-consumption and high self-sufficiency quota,
- high grid serviceability, and
- low vulnerability and high resilience.

As a consequence, the topics resource consumption, costs and energy supply were identified as main concerns for the physical infrastructure.

In this context, energy supply must be seen in the light of the aspects of own-consumption quota, self-sufficiency quota, share of renewable energies, electrification of transport and heat, grid efficiency and local energy trading. The goal of the ENaQ project is local energy trading among neighbours, so that local energy supply is the focus and externalization of resource procurement is to be explicitly reduced, but not completely avoided. In other words, the goal is to create a neighbourhood that relies as much as possible on own-consumption, but is not completely self-sufficient or entirely independent of an external grid. The neighbourhood may very well relay on an external grid.

Each of the topics resource consumption, costs and energy supply can be described by several indicators that are commonly and readily used to quantify the characteristics of energy supply systems in neighbourhoods. As an example, for the topic of resource consumption, GHG emissions, electricity consumption, heat consumption as well as relative exergy consumption, building energy consumption and e.g. land sealing can be mentioned. The indicators in general should be recorded for the district in the future in order to compare the district with other districts.

To optimize the energy system, emissions, costs and own-consumption were selected as key performance indicator (KPI) from the previously determined indicators. The background for this choice of KPIs is that they are intended to span a solution space that maps stakeholder concerns (Schmeling/Schönfeldt/Klement et al. 2020). In this way, conflicting requirements in particular are to be considered. Correlating indicators do not open any new dimensions and do not contribute substantially to gaining knowledge; on the contrary, they may lead to unnecessary consumption of resources when optimizing the energy system. The remaining indicators that were not selected as KPIs were consequently neglected for optimization.

While the definition of costs and own-consumption was relatively straightforward, various options where discussed about the aspect of emissions attributed to grid electricity. Consistency requires that grid supply and feed-in have the same absolute value, as electricity passing through the area does neither cause nor prevent emissions. To facilitate transferability, the (time dependent) emission factor of the electricity mix is considered. Other choices, i.e., the last power plant in the merit order, would have caused inconsistencies when being applied to many local energy systems at once. Details on the actual calculation of the KPIs were published by (Wehkamp/Schmeling/Vorspel et al. 2020) and (Schmeling/Schönfeldt/Klement et al. 2020).

3.2.2 Pareto-Optimization of Energy Systems

With defined goals and connected indicators, there are two options regarding optimization. One option would be to agree on one outstanding KPI which is then used for optimisation. This also might be a newly formulated compound KPI that integrates weighted indicators into one. Multi-objective optimisation marks the second option. It allows for late weighting by picking one of many pareto-optimal design options. However, it increases the computational effort. To tackle this, the operation of the possible energy systems was split into a separate, linear optimisation. This optimisation is purely economic and just minimizes operational costs, modelling a possible commercial operator. A schematic of the concept and a set of example results are displayed in Figure 3.1. The detailed procedure for optimisation can be found in (Schmeling/Schönfeldt/Klement et al. 2022).

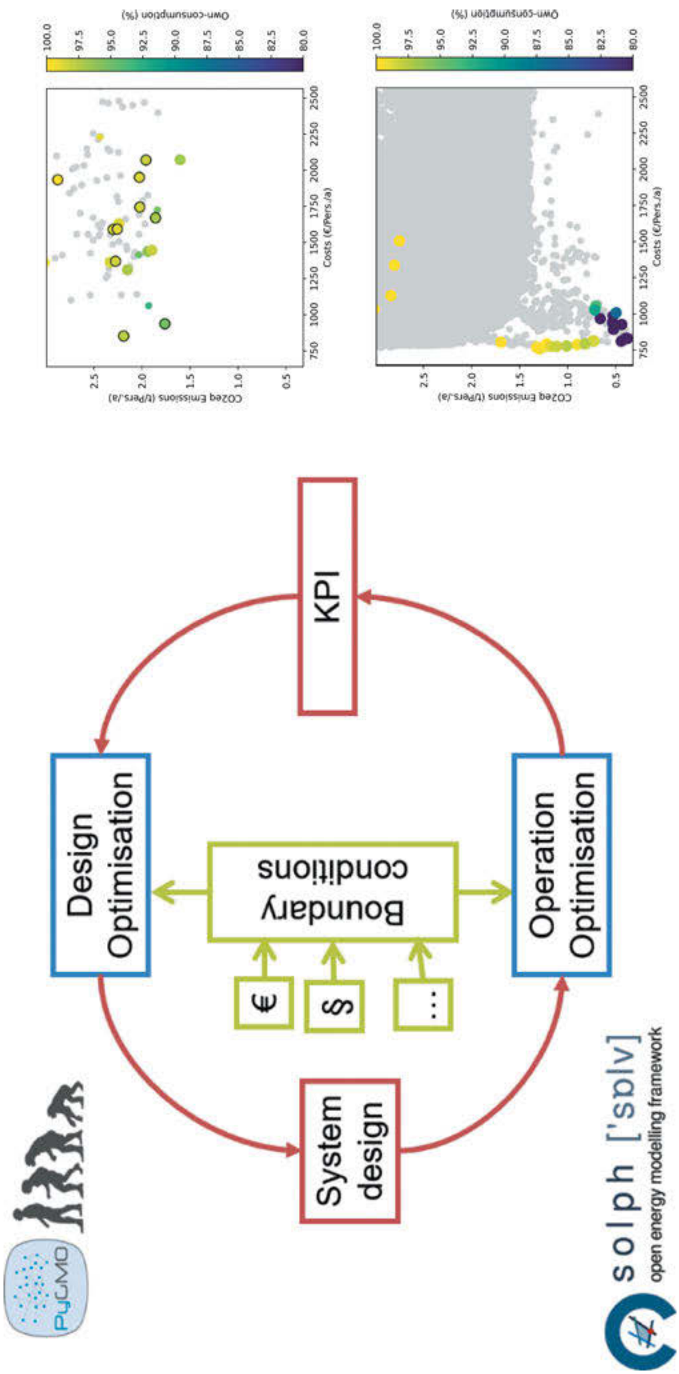

Figure 3.1: Schematic process of energy system optimization (left) and example Pareto-optimal systems after initialization (top right) and after optimization (bottom right). In the results, every dot marks a possible system design, the coloured ones are pareto-optimal.

The selection and design of the supply concept cannot be made purely based on technical requirements and certainly not without considering several boundary conditions. These will therefore be briefly outlined below.

3.3 Boundary Conditions

3.3.1 Legal Boundary Conditions

Since the energy supply concept under development is planned to be realised and operated, the current German legal framework conditions must be mapped as accurately as possible. This applies, of course, to laws on the supply of energy to private individuals, but also, for example, to the funding of renewable energies.

Another important point are the taxes and levies to be paid. These are usually independent of the distance between the producer and the consumer.[3] This would make it economically unattractive to produce and consume energy on site. A solution is to set up a customer system (Kundenanlage[4]). The customer system is not part of the public grid[5] and is only connected to the public grid at one point. The district then forms a single unit that can operate as a cohesive unit with respect to the public grid. For electricity generated and consumed within this customer system, only the EEG (German Renewable Energy Sources Act) levy, which is charged to refinance the funding of renewable energies, must be paid. Grid fees and taxes do not apply. More details on this topic can be found at (Brandt/ Schmeling/deBronstein et al. 2021, Katic/Schmeling 2022).

Likewise important for the design of the energy concept are minimum requirements for the energy supply of buildings, which in Germany are bundled in the GEG (Gebäudeenergiegesetz – Building Energy Act). On the one hand, this sets an upper limit for the primary energy factor of the energy supply and the transmission heat coefficient of the building envelope based on the technical standard (DIN V 18599:2018–09 2018). While the latter is determined purely by the building and therefore cannot be influenced by us, the primary energy factor can be significantly influenced by a more efficient, renewable energy system, which may make it possible to obtain higher subsidies. The GEG also specifies a minimum level of renewable energy to be used for heat supply, which can usually be achieved with solar thermal energy, or alternatively using heat pumps (HPs), combined heat and power plant (CHP) units, or pellet boilers, for example.

3 § 17 Nr. 1 StromNEV (Stromnetzentgeltverordnung – Electricity Grid Charges Ordinance).
4 § 3 Nr. 24a EnWG (Energiewirtschaftsgesetz – Energy Industry Act).
5 § 3 Nr. 17 EnWG.

3.3.2 Economic Boundary Conditions

The economic boundary conditions include, on the one hand, external conditions, e.g. especially related to the energy industry, and, on the other hand, internal conditions, such as the business models used. The external economic boundary conditions are largely dependent on the legal framework outlined in the previous chapter, as the energy industry is strongly regulated due to its (partly) natural monopoly. The use of external electricity markets is particularly important for the design of the energy concept. These are described in detail for Germany by (Klement/Brandt/Schmeling et al. 2022). We assume here that the neighbourhood obtains all its electricity on the day-ahead market and sells surplus electricity on this market if legally necessary.

The fact that the district acts as a single player in this market is possible due to the customer system. The organisation of this is done by a new market player, the district aggregator. In addition, this aggregator establishes local energy trading among neighbours, i.e., it allows electricity to flow between different participants within the neighbourhood without having to face too high legal, bureaucratic and organisational hurdles. More details on the neighbourhood aggregator can be found at (Brandt/Schmeling/deBronstein et al. 2021, Katic/Schmeling 2022).

3.3.3 Technical Boundary Conditions

The planned district consists of seven buildings that will be connected to a district heat network with a central heat supply. A sketch of the energy system design is depicted in Figure 3.2. The model has been released as open-source software (Schönfeldt/Schmeling/Wehkamp 2021).

To have redundant heat supply in case a combined heat and power plant (CHP) must be maintained, the investor requested that gas boiler, pellet boiler, and HP are sized large enough to fulfil the peak demand

$$\max(P_{\text{demand, th}}) \leq P_{\text{gas boiler}} + P_{\text{pellet boiler}} + P_{\text{heat pump}}. \tag{3.1}$$

This way, shortages or reliance on power to heat (P2H) can be excluded even in case of unplanned operation conditions.

3.4 Input Data

The subsequent simulation is based on calculating and evaluating the behaviour of the energy system in an hourly resolution. For this reason, it is necessary to model the temporally variable boundary conditions as (at least) hourly time series. To be able to trace the later simulation results back to their influence, the relevant time se-

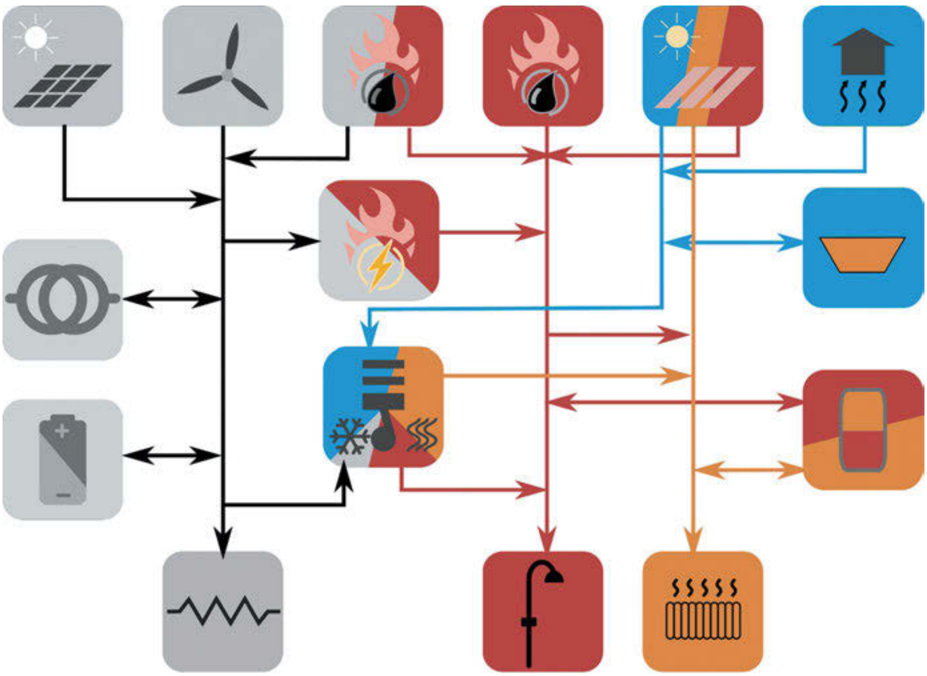

Figure 3.2: Graph of the energy system template including all considered technologies. The icons represent (left to right, top to bottom) photovoltaics (PV), wind turbine (WT), CHP, boiler, solar thermal (ST), ambient heat, grid electricity, power to heat (P2H), seasonal storage, battery, heat pump (HP), warm water storage, electricity demand, domestic hot water (DHW) demand, and space heating (SH) demand.

ries and their origins are to be explained. Both external boundary conditions, which can be divided into environment and market, and internal boundary conditions, i.e. the energy demand of the buildings, are relevant.

It is important to use data from one common year, as many of the variables influence each other. For example, it would be mistaken to combine meteorological data from one year, electricity market data from another and electricity demand data from a third, as these are all interconnected. Various factors must be considered when selecting the relevant year. On the one hand, the year should be as current as possible to have realistic market prices. Secondly, the year should contain a cold period so that the energy supply will work under these conditions. After extensive research, we decided on the year 2017.

3.4.1 External Conditions – Meteorology

A decisive factor for the energy demand of buildings, but also for the generation of renewable energies, is the weather. Various parameters come into play in this context. It is possible to obtain this data either as measured data from a nearby weather station or as a numerical weather prediction, i.e. interpolation of a weather model. Due to data quality and availability, we use freely data from the nearest weather station of the German Weather Service (DWD). This is located at the airport in Bremen, approx. 43 km east of the neighbourhood. The location is in the same climate zone and can therefore be used without restrictions.

Relevant meteorological variables are the outdoor temperature, e.g. for the heat demand of the buildings or the efficiency of a PV system, the direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI) for the yields of the photovoltaics (PV) system, the ground temperature for the efficiency of a geothermal heat pump (HP) and the wind speed for the yield of the wind turbine (WT). The greatest impact is exerted by the air temperature and the two radiation time series, which are shown in Figure 3.3.

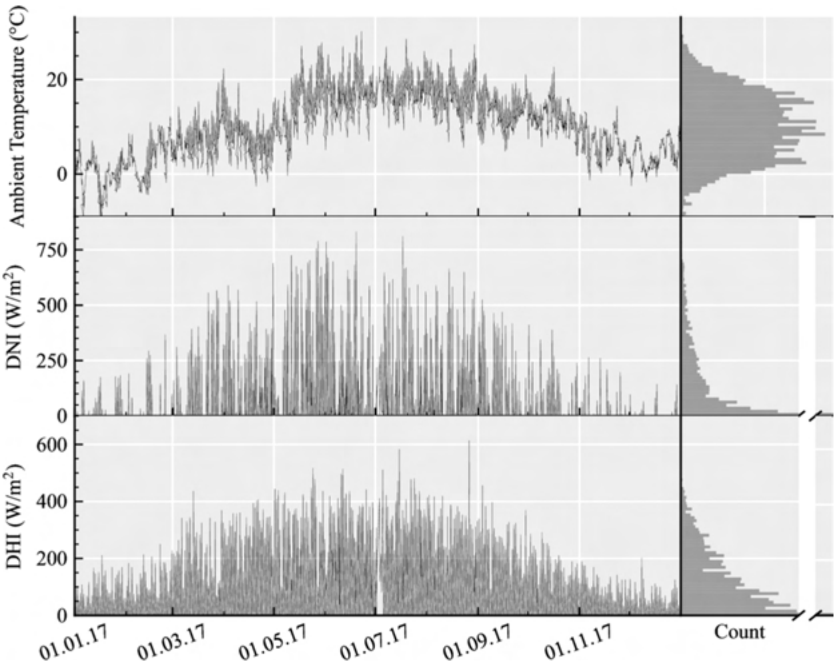

Figure 3.3: Visualization of the most relevant meteorological time series for the optimization and simulation of the energy system.
(Source: Deutscher Wetterdienst (DWD))

3.4.2 External Conditions – Grid Electricity

As already mentioned in 3.3, the district electricity market interacts directly with the national day-ahead market by buying missing energy and selling excess energy. Figure 3.4 shows the time course of prices on this market.

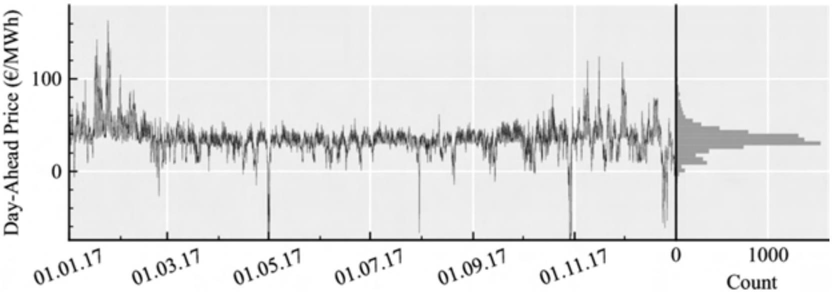

Figure 3.4: Visualisation of the electricity price of the day-ahead market for the DE-LU bidding zone. (Source: ENTSO-E Transparency Platform)

In addition, there are of course, depending on legal requirements, taxes and levies, which in total are significantly higher than these pure energy purchase costs.

The procurement of electricity available at this market is of course also associated with climate-damaging emissions, as fossil-fuel power plants are still operated extensively here. It is important to note that the composition of the electricity mix changes permanently due to volatile renewable energies. This does not only happen locally, but in the entire European interconnected grid. With the help of a flow tracing algorithm (Bialek 1996, Hörsch/Schäfer/Becker et al. 2018), the electricity flows and proportional shares can be broken down and transferred based on technology-specific emission factors to a temporally resolved electricity mix of the German market (Windmeier 2019). The time series of the intensities of electricity procurement can be seen in Figure 3.5.

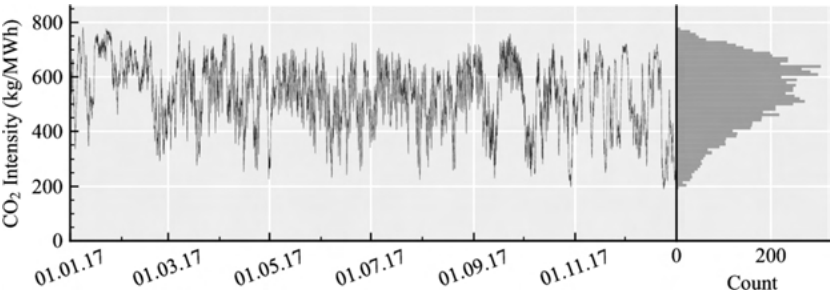

Figure 3.5: Visualisation of the CO_2 intensity of the mean German electricity mix, determined with the help of a flow-tracing approach from ENTSO-E Transparency Platform data.

Another relevant aspect is how the market costs and the associated emissions are linked. For this purpose, the correlation of the two time series can be seen in Figure 3.6. Both correlate positively with each other, linearly in the primary region. This is mainly due to the subsidies for renewable energies in Germany, in which large plants are no longer subsidised on a flat-rate basis, but their electricity must be marketed on the stock exchange. As these electricity volumes are usually generated in larger quantities due to meteorological dependency, this leads to a shift in the supply curve and thus to a reduction in prices. In contrast to other areas of life, purely economically oriented action thus usually has a positive ecological impact.

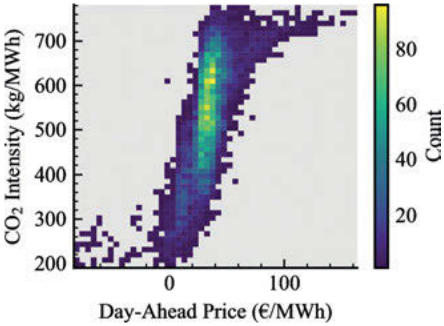

Figure 3.6: Visualisation of the correlation between electricity market prices (Figure 3.4) and CO_2 intensities (Figure 3.5) as a 2D histogram.

3.4.3 Energy Demands

To match the energy system to the building to be supplied, their energy demand must be determined, as well as the temporal course of this demand.

The electricity demand is the easiest to determine, as it is largely dependent on the occupants and their behaviour. Assumptions were made regarding the resident structure, household size, age and employment status based on similar objects in the real estate developer's portfolio. With the help of the LoadProfileGenerator (Pflugradt/Muntwyler 2017), a software tool for creating synthetic load profiles based on a behavioural simulation, these structures were translated into an hourly load profile of the entire neighbourhood. The result can be seen in Figure 3.7.

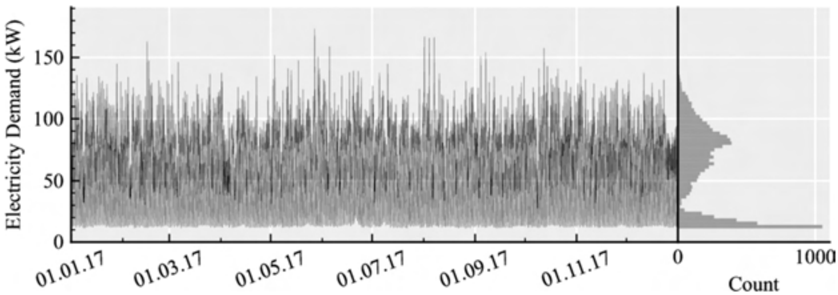

Figure 3.7: Visualisation of the electricity demand of the district.

Using the same methodology and the same tool, the DHW demand was determined, which can be seen in Figure 3.8. This demand is initially stated here in litres and must later be translated into different thermal or electrical demands for DHW production, depending on the DHW concept.

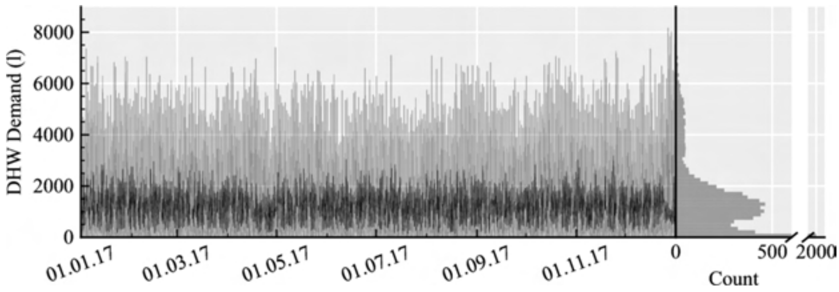

Figure 3.8: Visualisation of the DHW demand of the district.

The space heating (SH) demand of buildings is more difficult to determine, as it depends not only on user behaviour but also on building physics. With the help of the software QuaSi (Technical University of Braunschweig – Institute for Building Services et al. 2020), simplified cubatures, building material properties, weather data and usage profiles were defined for each building to simulate the buildings energetic behaviour and thereby create hourly load profiles for SH using a generic thermal building model based on EnergyPlus® (Crawley/Pedersen/Lawrie et al. 2000). These were compared to the annual heat demand according to energy performance certificates following (DIN 4108–6 2003) and scaled accordingly. However, since part of the SH demand does not have to be covered by the heating system, but instead is covered by internal gains from electricity usage, the electricity demand time series was subtracted from the previous SH time series, which, of course, can never be less than zero. This results in the time series of the SH demand of the buildings shown in Figure 3.9.

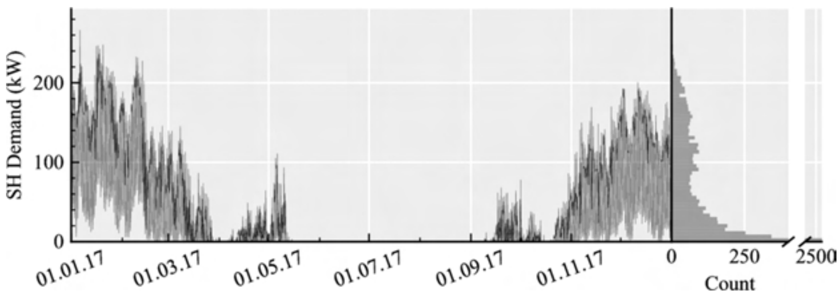

Figure 3.9: Visualisation of the SH demand of the district.

The SH and DHW requirements of the buildings have so far only been determined for each building individually. However, as there will only be one central heating system, the heat will have to be distributed via a district heating network. This is associated with heat losses that the energy system must provide in addition to the actual demand. These losses are determined according to a methodology described by (Vorspel/Bücker 2021, Wehkamp/ Schmeling/Vorspel et al. 2020) and thus results in the heat time series to be provided at the outlet of the central heating system. To keep the grid losses low, it helps to operate the grid at as low a temperature as possible. This is especially possible if the DHW concept realises legionella-free conditions in another way. Figure 3.10 therefore shows the heat demand at the outlet of the heating centre for a heating network at 40 °C and 80 °C flow temperature.

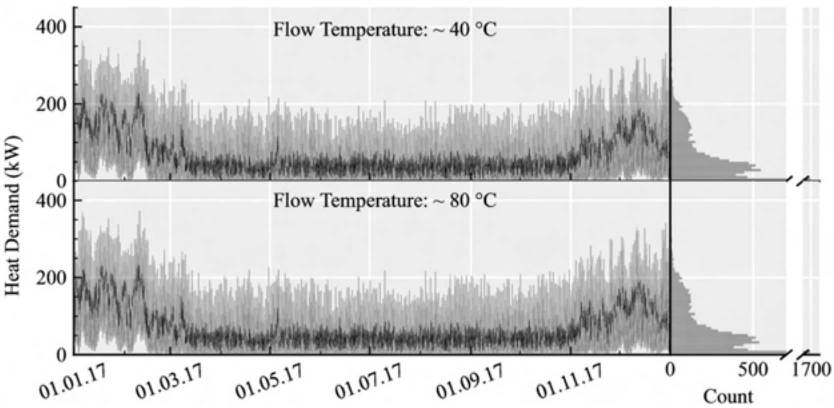

Figure 3.10: Visualisation of the heat demand of the district, as it is to be provided from the heating centre, for different temperatures of the heating network. On average, the higher temperature increases the losses, and thus the demand by 5 %.

3.5 Results

As the demands are almost constant over the three concepts, it is expected that they can reach similar combinations for costs and emissions. While this is particularly true for the minimum emissions that can be reached (0.5 t/Pers/a) and because additional investment can significantly reduce emissions until this minimum is reached, the costs significantly deviate (cheap: 550 EUR/Pers/a to 600 EUR/Pers/a, low emissions: 650 EUR/Pers/a to 800 EUR/Pers/a).

An overview of the pareto-optimal solutions is displayed in Figure 3.11. It shows that most solutions strongly integrate the heat supply with the electricity sector, using CHP or HP. We observe three groups of solutions: For all three DHW supply options, the lowest emissions are achieved if the electricity grid is avoided as much as possible at expensive and therefore high-emission times. As electricity fed into the grid can balance for negative emissions (Figure 3.5), the solutions featuring the lowest emission all focus on CHPs. A further reduction of the emissions is not possible without increased production of electricity, thus the available area for PV and the heat demand (via demand for heat covered by a CHP) define the lower end of the emissions. This also explains why a slightly higher demand in the 80 °C scenario does not come as a disadvantage for these solutions. It should be noted that this strategy can only work if CHP electricity has lower emissions than grid electricity (Klement/Brandt/Schemling et al. 2022).

Solutions with emissions between 1.0 t/a and 1.5 t/a are dominantly supplied using geothermal (GT) and ST. The latter is the most relevant heat supply technology that is not coupled with the electricity sector. However, solutions with GT or ST heat sources seem not to be competitive under the assumed conditions if DHW temperature cannot be supplied by the heat network. While these supply options mark the compromise between costs and emissions in the other two DHW treatment options, electrical boosters mostly drive them out from the space of pareto-optimal solutions. Boilers (both, gas and pellet) do not account for most of the heat in any of the energy system designs, still they serve as backup in these GT and ST options. Gas boilers, however, provide about half of the heat in more traditional CHP concepts which mark the low-cost/high-emission end of the scale in Figure 3.11.

At this point, it should be noted that the requirement of redundancy as described in Eq. 1 is not optimally chosen. As the operation is optimised purely economically, installed gas boilers would be used not only as a backup. Consequently, the heuristics found solutions with the lowest emissions when building pellet boilers or heat pumps as backup devices. In the concept S. 3, the solution with big HP do not use these with a GT source, instead they serve as power-to-heat (with a coefficient of performance (COP) of 1). This can be seen as there are HPs without geothermal coverage. On the other hand, pellet boilers are never used but just chosen to fulfil Eq. 1 without having a gas boiler. This fact shows that the role of the heat sector as a provider of flexibility in the electricity sector cannot be emphasised too much.

The presented results suggest that the principle advantages and disadvantages of supply technologies are not fundamentally different for the investigated temperature levels. A higher temperature increases costs, especially of the solutions based on heat-pumps, but they remain pareto-optimal. On the other hand, increased electricity demand due electric heating of DHW becomes a problem for heat pumps, if they compete for the same (local) renewable electricity.

It should be noted that these results were obtained for new buildings with a rather high population density. We expect the situation to be different, i.e. when more local renewable energies are available per person or the influence of DHW on the overall heat demand is reduced.

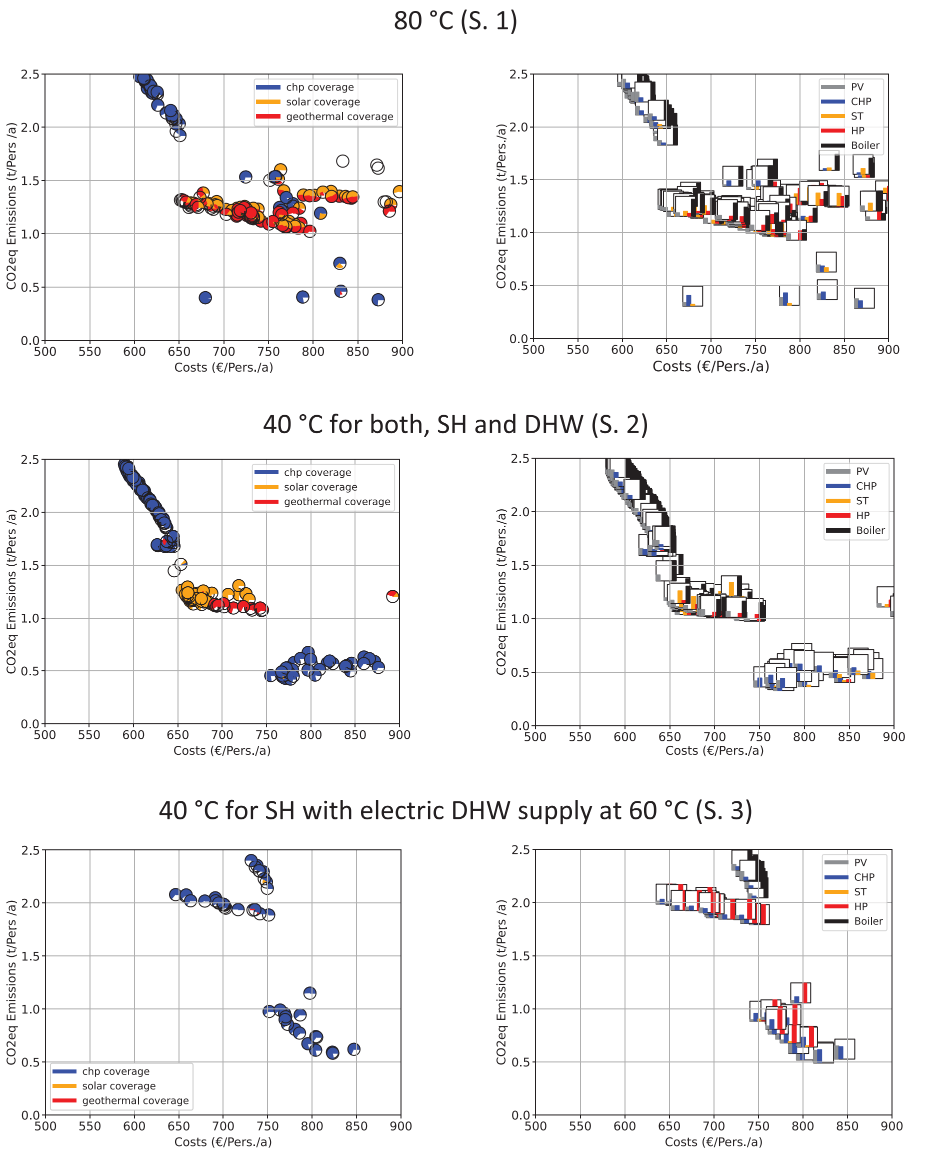

Figure 3.11: Left: Contributions of different heat supply technologies to the total demand. The white areas represent heat covered by either gas boiler (if present) or power to heat. Right: Size of generation technologies. The size of the bars is relative to the maximum size (PV: 500 kW, CHP: 150 kW (electric), ST: 415 m^2, HP and boiler: 670 kW). Own-consumption increases from the lower left hand side to the upper right hand side. It is not displayed explicitly because most solutions reach quotas of at least 70%, which is also the reason why pareto-optimal solutions in the upper right-hand corner are rare (cf. Figure 3.1, which shows S. 3).

3.6 Summary

We presented a concept for energy system design for the ENaQ project that simultaneously optimises indicators representing the interests of different stakeholders. We find that flexibility in the heating sector is a key for low emissions. Regular operation of gas boilers must be avoided. Furthermore, we compared three centralised DHW supply concepts, finding that rising the temperature electrically eliminates solutions relying on GT or ST.

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Alexander Hill, Christian Pieper, Tobias Brandt

4 District Energy Management Scheduling using a Participatory Local Energy Market

Summary: Changing the energy supply system to reduce greenhouse gas emissions is a huge challenge on many different levels. In the urban environment, district level solutions for heat and power supply offer a multitude of improvements when it comes to integrating renewable energy sources, reducing energy prices for customers, and reducing the impact of renewable energies on the power grid. These goals can be achieved by managing the local energy systems, optimize schedules for costs, CO_2 emissions, and wear. Furthermore, the system can be used to inform customers to make better decisions about their consumption.

This paper describes a software system architecture design for a district energy management system. The focus lies on managing diverse energy systems within an urban neighbourhood while providing information to interested parties to manage the system or to provide further services. It is shown that a variety of different energy systems can be integrated using Internet of Things and cloud technology to optimize the system operation.

4.1 Introduction

The efforts to reduce greenhouse gas emissions in the electricity generation ask for new solutions on different levels of the electricity grid. On the one hand, an increasing amount of renewable energy sources that are needed puts stress on the power system. Peak demand on consumer-side and peak generation times and location from renewable sources often do not match, resulting in large amounts of electricity needed to be transported over the power grid, which can get congested (Hitaj, 2015). On the other hand, modern electricity consumers such as Heat Pumps (HP), electric vehicle charging, and H_2 production offer new possibilities for an intelligent Demand Side Management (DSM) (Salpakari, Mikkola and Lund, 2016).

Additionally, the individual heat and electricity consumption of a single household is poorly predictable due to individual behaviour of residents, for example different routines on business days and weekends. This makes the management of the

Alexander Hill, OFFIS e.V. – Institute for Computer Science, R&D Devision Energy, Escherweg 2, 26121 Oldenburg, e-mail: alexander.hill@offis.de
Christian Pieper, OFFIS e.V. – Institute for Computer Science, R&D Devision Energy, Escherweg 2, 26121 Oldenburg, e-mail: christian.pieper@offis.de
Tobias Brandt, OFFIS e.V. – Institute for Computer Science, R&D Devision Energy, Escherweg 2, 26121 Oldenburg, e-mail: tobias.brandt@offis.de

https://doi.org/10.1515/9783110777567-004

energy system a difficult task. However, developing an energy management system for multiple households can alleviate this problem due to the fact that individual consumption has a lower impact onto the whole consumption of the district.

Managing a local energy systems is a non-trivial task. Information from different sources have to be gathered and analysed to have an accurate view of the current situation. Based on this information, decisions have to be made on how to control the available energy systems within the neighbourhood. For example, in case of decreasing electricity demand but increasing electricity generation by PV modules, a local battery or power to heat system could be activated to store energy, which then can be used at times where the local electricity demand exceeds the generation. The decisions, in turn, have to be communicated back to the energy systems so that they can execute them. On top of that, the residents of the neighbourhood can be included in the energy system, e.g., by informing them about their electricity consumption and CO_2 footprint.

Additionally, without accounting for information about regional energy generation outside the neighbourhood, it is more likely to emit more CO2. Intelligent load shifting can alleviate this problem while also providing a high self-consumption rate of electricity. Take for example a cloudy and windy day with a calm night and nearby wind turbines connected to the grid and a neighbourhood with PV and a charged battery. If we do not consider the wind park outside the neighbourhood and would consume energy over the day, battery power would be provided. However, since it is windy, near wind turbines make the local grid energy produce less CO2 and it would be better for local CO2 emission to provide the battery power at night. This benefits the residents and electricity consumers of the neighbourhood and relieve the electricity grid since the locally produced wind electricity is consumed near the production site. With dynamic energy prices, this could also provide monetary advantages since the grid power at night will cost more than at the day due to lower wind power generation.

To achieve these goals, a managing software is needed that is capable of gathering large amounts of diverse data, analysing these, being able to communicate information back to third parties (such as user interfaces for the residents), controlling local energy systems, among other requirements (Piette/Singh/Prakash 2019). In a wider view, the system also needs to be able to communicate with other systems that control parts of the energy system, e.g., the low voltage grid management system, other neighbourhoods, industrial complexes, or large campuses.

In this paper, we describe such a local energy management system with a focus on its architecture and interfaces to other interested parties. The system is called Quarter Energy Management System (QEMS), where “quarter”‘ (German, “Quartier”‘) stands for a neighbourhood or small city district. Our aim is to provide a framework in which different parties, for example a grid aggregator and local residents, can participate together to optimize the production and consumption of thermal and electrical energy in a live setting. Another aim is to make the system optimization algorithm agnostic, which in turn makes it possible to compare different optimization strategies with each other for the same environment. For this, data about the current system and forecasts are collected and passed to a selected optimization algorithm and distributed to the different devices afterwards. To ease the calculation part, the system is also able to group and summarize different systems of the same kind and can distribute grouped load accordingly to the single systems. In addition to the optimization, we also want to provide ways to learn that there are better and worse times to consume electricity as inhabitant. Therefore, we developed an energy feedback system indicating good and bad timings for energy consumption, which will be integrated to the corridors of all flats. As it works with different lights, we called it energy signal light (Klement/Lanezki/Schmeling et al. 2022). The paper is structured as follows. Section 4.2 gives an overview of the related work in the area of District Energy Management Systems (DEMS). Section 4.3 details the system environment, which is an important factor for the design decisions and the architecture described in Section 4.4. The experimental setup of the system is described in Section 4.5 and Section 4.6 concludes the paper and shows future work on this topic.

4.2 Related Work

There are several types of Energy Management Systems (EMS), most notably Home Energy Management Systems (HEMS) and District Energy Management Systems (DEMS). All these EMS share similar goals, for example minimize cost or maximize profit, maximize self-consumption or minimize CO_2 emission or a combination out of these goals.

Shareef et al. (Ahmed/Al Hassan/Shareef et al. 2018) give an overview of the development of HEMS, as well as of the different types and techniques used, for example, to incentivize users to shift the power consumption to off-peak times via Demand Response (DR), and to calculate good schedules for controlling the devices.

Due to volatility, not only from renewable energies, but especially from energy consumption of residents, scaling the systems to multiple households make sense to smooth the overall consumption. However, HEMS does not scale well for multi-apartment buildings. This is where DEMS comes into play. DEMS are similar to HEMS, but use a whole city district, campuses (Talei/Essaaidi/Benhaddou 2017) or large buildings (Cipcigan/Javed/Marmaras et al. 2017) of varying sizes to shift and reduce energy loads. A precondition for a DEMS is the availability of a District Energy System (DES), i.e., a controllable system that provides electricity, heat, and / or cooling for a city district or a neighbourhood. Alternatively, a DEMS can also control the demand side via DR. Similar to HEMS, the goals for DEMS often are on the one hand to (1) decrease the usage of fossil fuels compared to only grid-connected households and house-internal heating supply and on the other hand to (2) do peak-shaving to lower the stress on the power grid (Bibri 2020). A DES could also be an integration of multiple HEMSs (Fanti/Marcello Mangini/Pizzuti et al. 2015) which have the energy systems under their control and interact via the DEMS. DEMS often leverage current trends in information technology to improve their results, i.e., connecting devices and collecting data via the

Internet of Things (Acquaviva/Brundu/Giudice et al. 2017), managing the data in cloud applications [5, 6], and using the data for data-driven decisions (Bibri 2020) and machine learning applications such as power consumption forecasting (Ahmad/Chen/Huang 2019).

Patti (Acquaviva/Patti/Sciacovelli et al. 2014) presents a cloud based DEMS that combines sensor data and static data from a Building Information Model to monitor and control the energy consumption and generation in a city district. Additionally, the data is used to increase the user's awareness in terms of energy consumption. Interoperability between different devices and protocols is a key goal of the work. This is achieved with a layered architecture that utilizes proxy interfaces to integrate different device protocols such as Open Platform Communications (OPC) unified architecture and ZigBee. Different to this work, (Acquaviva/Patti/Sciacovelli et al. 2014) focuses mainly on collecting data from the field devices, having less emphasis on the scheduling and controlling of the devices. Talei et al. (Talei/Essaaidi/Benhaddou 2017) describe how a cloud-based system could be used for energy management on a campus and (Cipcigan/Javed/Marmaras et al. 2017) also use a cloud-based system for energy management in large buildings, especially for peak shaving. Next to the cloud technology, IoT plays an important role in DEMS to connect the field devices with the software system (Acquaviva/Brundu/Giudice et al. 2017).

Brusco (Brusco/Burgrio/Menniti et al. 2014) presents a DEMS with the focus on prosumers, i.e., consumers that also produce electricity, e.g. via a photovoltaic (PV) system. They are connected in a coalition with a coalition coordinator, whose goal is it to maximise the utility of the coalition of prosumers in their energy district. The coalition coordinator is similar to a district aggregator, a role used in the system model of this paper, but does not directly control the participating devices. Similarly, Ma et al. (Jianhua/Liu/Ma et al. 2019) present a cooperative trading mode for prosumers in an energy hub. Joshi et al. (Joshi and Ramamritham 2019) present a management system for a shared community battery. The system is meant for a community with prosumers that have rooftop PV installations and aims to "reduce energy costs and reliance on grid supply" (Joshi and Ramamritham 2019).

DEMS can be integrated into a smart grid to take an active role in it. A model to embed DEMS in a smart grid is the approach of a cell-based energy system (Lehmann/Huber/ Kiesling 2019). Here, the smart grid is organized in energy cells. These cells are spatially limited and can autonomously manage their own power generation and consumption. They are connected to their adjacent cells and share information and energy with them. Cells can also be aggregated to larger cells (Lehmann/Huber/Kiesling 2019).

O'Dwyer et al. (Butler/Charlesworth/O'Dwyer et al. 2020) present another approach to an DEMS architecture with the emphasis on the integration of digital twins. They implemented an optimization-scheduling algorithm that consists of sub-systems that optimize their respective systems while a coordinator also checks that overall constraints are met. It is also shown that their framework is modular by providing simulations for three different scenarios with different optimization goals, a hybrid heating scenario, an electric vehicle charging with PV plants scenario and coordination scenario, where two sub-systems need to balance the electrical power demand for each other.

While these works all have a framework with scheduling and device control, they focus mainly on optimization. To the best of our knowledge, no other framework incorporates different goals, for example requirements from a grid operator and the reasons to use a local grid ("Kundenanlage") in Germany. This work instead shows which information interfaces are interesting for different parties and how we incorporated these into a device optimization and control framework.

4.3 System Environment

District Energy Management Systems (DEMSs) can operate in different settings and environments, both from a regulation as well as a technical aspect. The system environment has an effect on the implementation details of the DEMS. Important aspects are the ownership of the controllable devices, the level of control over the devices, system size, regulatory limitations, and market design, among others. In the following, the main aspects of the targeted system environment for the Quarter Energy Management System (QEMS) are explained.

4.3.1 The District Aggregator in Energy Neighbourhoods

The focus of our work lies on neighbourhoods with a shared energy system. Neighbourhoods are spatially clearly definable residential areas with multiple buildings consisting of either single-family houses, apartment buildings, or both. Smaller businesses such as a bakery or a kindergarten are also possible parts of such an urban area.

An energy neighbourhood needs, next to the technical implementation, a legal framework to operate in. A typical question would be how to trade electricity between residents of the neighbourhood who own PV systems, because in Germany, it is not possible to trade energy peer-to-peer easily due to regulations. To solve the problem, we add an intermediary to do the documentation and legal work for the electricity flow within the local grid – called aggregator.

For this work, we use the model of a district aggregator, which is depicted in Figure 4.1. The aggregator buys all locally generated surplus electricity (1) and sells it back to the neighbourhood (4). If the neighbourhood has surplus electricity, the aggregator sells it to the grid (2), if the neighbourhood needs external electricity, the aggregator buys it from the grid (4). Within the district, the district aggregator buys all surplus energy from the producers and sells it to the consumers.

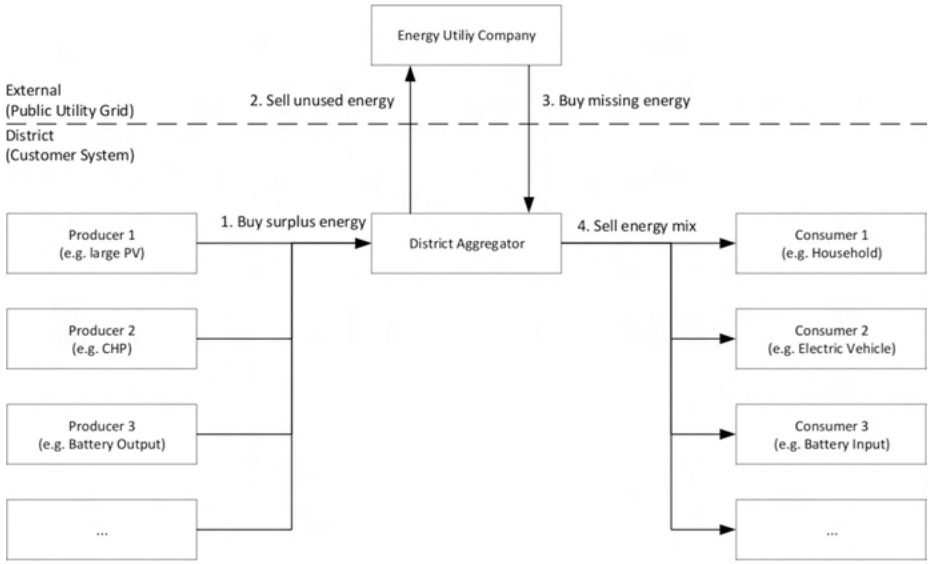

Figure 4.1: The role of the district aggregator in the local energy system. The aggregator gets a commission for enabling the market.
(Source: figure redrawn from Brandt/Schäfer/Schmeling et al. 2021)

In order to implement this behaviour, the aggregator manages a separate grid that is connected to the main grid on one entry point. This separate grid can now employ its own rules for all trades between participants in the local grid. However, since a separate grid infringes the basic principles of the liberalised electricity market, some conditions have to be met (Brandt/Schäfer/Schmeling et al. 2021).:

- The aggregator grid must be a closed local area of small scale (about a few 100 consumers, an area less than 10,000 m^2, less than 1 GWh of electricity consumption per year)
- Direct charges for using the grid must not be levied
- All citizens retain an opportunity to freely choose their electricity supplier

Not all requirements must necessarily be met exactly, but the conditions should not be stretched too far.

4.3.2 Energy Systems

Within an energy neighbourhood, different energy forms are available and different energy devices can be installed. On the one hand, the devices can be distinguished into consumers, producers, prosumers, and Energy Storage Systems (ESS). On the other hand, the devices can be distinguished by the energy type, mainly heat and electricity.

In our project, the system comprises of a Heat Pump (HP) per building, thermal and electric ESS and PV systems. The PV systems are also divided in Grid Aggregator plants and resident's micro plants that will be installed at the balcony (German: "Balkonkraftwerke"). In previous iterations a combined heat and power plant (CHP) was planned. Due to new regulations and funding, HPs were considered more viable. However, QEMS can be used with all of these energy devices types. In this work, it is assumed that a grid connection is available at all times. The goal is not to operate an isolated system.

It should be highlighted, that not all systems are owned by a single entity, but can be in the ownership of multiple entities. In an energy neighbourhood of our main scenario, all residents will have a balcony PV plant and are therefore prosumers. That means, they do not only consume energy, but also produce it. This gives a DEMS the possibility to control the devices in conjunction so that they can be optimized together to reach certain system goals.

4.3.3 System Goals

A particular aspect of the district aggregator is the monitoring and optimization of the local energy systems in the neighbourhood. As the system environment can consist of a wide range of equipment with different properties, this is a challenging task, which will most likely be taken over by a DEMS software, in our case QEMS. However, optimizing the energy systems could lead to different advantages, which we call system goals.

The system goals depend on the requirements of the system owners and neighbourhood residents and are measured with specific Key Performance Indicators (KPIs). The QEMS itself is agnostic to what it or its scheduling subsystem should optimize the schedules for. Currently, the system targets are reducing the CO_2 emissions, reducing the usage of electricity from the grid, increasing the self-consumption ratio of locally generated electricity, and reducing the overall costs.

4.4 System Architecture

In this section, we introduce and describe the system architecture of QEMS. The parts of the system can be divided into four main groups: (1) field device communication, (2) data management, (3) scheduling, and (4) information interfaces.

4.4.1 Software System Architecture

QEMS consists of many different parts and micro services, which makes it flexible when adapting the system to other system environments such as field devices, prediction and scheduling algorithms, and communication standards. Figure 4.2 shows an overview of the presented system. The field devices are depicted on the bottom. For the architecture, different communication systems are used, mainly Smart Meter Gateway (SMGW) based communication channels and custom communication channels, depending on the practical circumstances. Above the field communication layer is the main QEMS software system. The main communication channels are event based messages, which are send via a messaging system, where interested parties can subscribe to get specific messages that are published to the message bus. In our case, we use Advanced Message Queuing Protocol (AMQP). Another way we communicate with our services is via request-response based communication with Representational State Transfer (REST), where the host provides functions using a webserver, following a standardised naming convention. The data management is mainly done by service-internal relational databases for management data and a central time series database. For user-facing visualizations, a Grafana[1] web front end with custom plugins is used.

QEMS is designed to be deployed in a cloud environment and to communicate with the field devices via the internet. The services are deployed in Docker containers and share a common internal network, wherefore the internal communication is not reachable from the outside.

4.4.2 Field Device Communication

To control and optimize the local energy system, QEMS both needs to have a clear picture of the current situation in the field and also needs to be able to control some of the devices. Figure 4.2 shows the field level connection and communication infrastructure on the lower half. It can be seen that two different communication set-ups are possible. On the left, a regulated communication setup via an SMGW is shown, while on the right a custom field connection setup is depicted. QEMS supports both. On the higher levels of the communication infrastructure, similar technologies are used. For example, messaging systems such as Message Queuing Telemetry Transport (MQTT), AMQP or Kafka are used both in the custom setup as well as in the regulated setup.

To send control commands from QEMS down to the field devices, different abstraction layers are available. The depicted REST interface in the custom setup can be a high level Application Programming Interface (API) with a generic interface to con-

1 Available at: https://grafana.com/.

trol devices or be more low level by only forwarding commands to the respective machine interface. For example, the interface could offer a high level function to turn a device on and off or the interface could offer the possibility to write certain values into a Modbus address, which in turn can be used to turn a device on or off by writing the correct value to the correct address. The Controllable Local System (CLS) connection by itself does not offer such a high level interface, but it can be implemented as an additional service. Nevertheless, as shown in the following sections, QEMS is concentrating the device specific knowledge in the device specific services.

4.4.2.1 Smart Meter Gateway Communication Setup

An SMGW is a regulated gateway in Germany, mainly meant for the energy domain. The goal is to support the energy transition to renewable energy sources with a digital smart grid, in which the SMGW offers a standardized and secure communication infrastructure (Bundesamt für Sicherheit in der Informationstechnik, Bundesministerium für Wirtschaft und Energie, 2019). The rollout of these devices has started in 2020 for households with an electricity consumption above 6000 kWh per year, among others (Bundesministerium der Justiz, 2016). SMGWs have an internet connection, which can be used to share meter data but also as a secure connection to controllable devices such as battery systems via the so-called CLS interface (Bundesamt für Sicherheit in der Informationstechnik, 2019).

As can be seen in Figure 4.2 on the bottom left, the local meters, mainly for electricity and heat, are connected to the Local Metrological Network (LMN) interface. The meters send the data to the SMGW gateway manager entity, which then shares the data to authorized parties. In this setup, AMQP is used for the last step, but this is not necessarily the case, as the technical implementation is not part of the regulation. The CLS interface on the other hand allows to have use-case agnostic transparent communication channels to devices that are connected to the SMGW on a specific Ethernet port.

This CLS interface can be used to control devices such as batteries or read values from PV meters. Additionally, we use a protocol converter device, e.g., to convert custom control messages into Modbus or other device specific protocols. This allows the system to be device agnostic in higher layers.

4.4.2.2 Custom Communication Setup

The right side of Figure 4.2 shows the custom field connection setup, which is build up similar, but does not use the SMGW infrastructure. In this case, the protocol converter device is connected to a control application, here depicted in blue. It consists of a messaging system to share sensor data from the devices, such as the current battery state

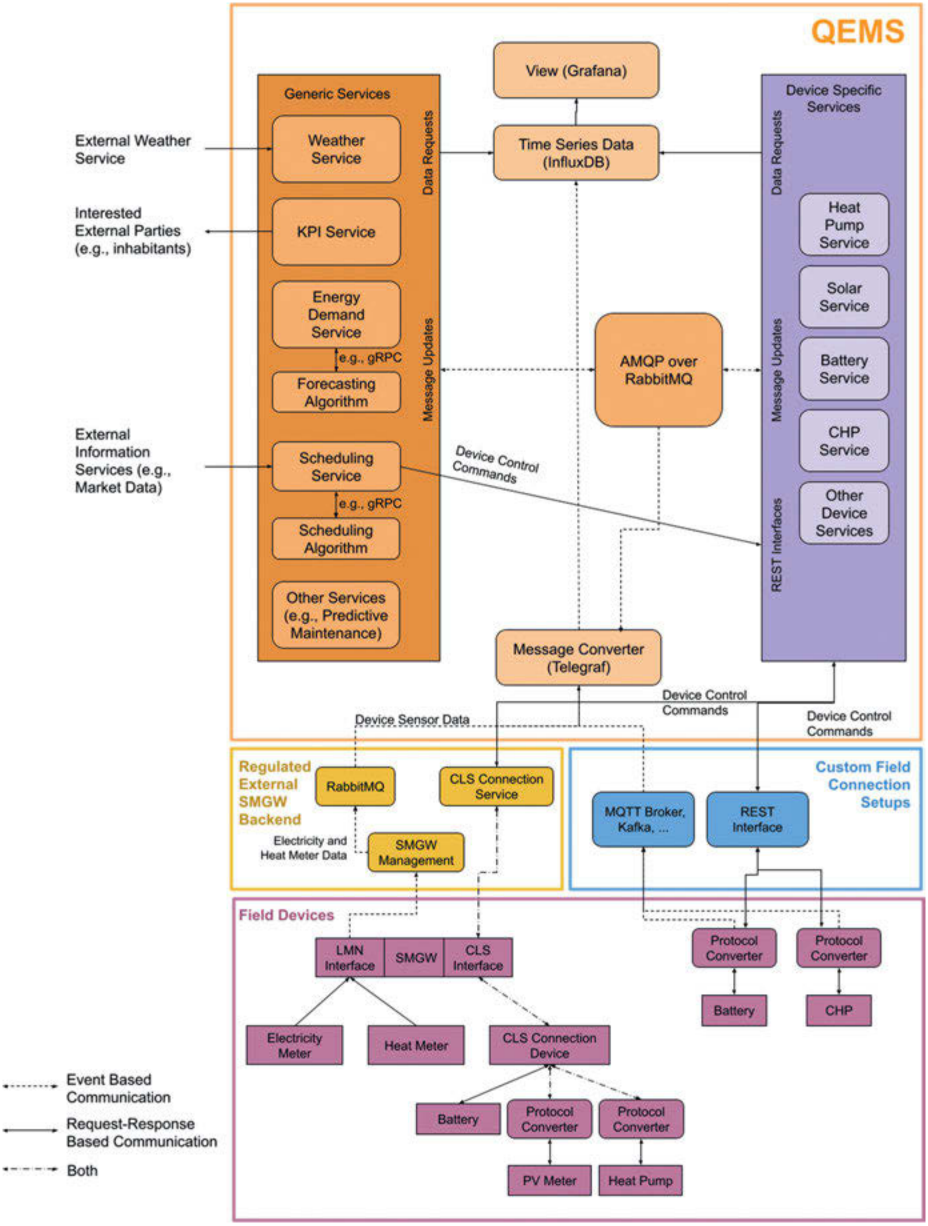

Figure 4.2: Architecture overview of QEMS from field devices to user front end. For device specific services, multiple forms of connection to the devices are possible e.g. via SMGW CLS interface or a simple REST Interface.

of charge. Additionally, it offers a REST interface for control commands that have to be sent to the devices.

4.4.3 Data Management

The messages from the different field devices and services, such as time related data, are collected, converted and send to a storage by Telegraf,[2] a simple software to receive and convert messages from different sources. After conversion, Telegraf pushes the data into our time-series database, namely InfluxDB.[3] Services can read from this database if they need data for a specific time interval or in an aggregated form. For the most current data, the services use the messages they subscribed to from the message broker. Services cannot write into the database directly, as this would be a source for write conflicts. The incoming message conversion is individually crafted for every use-case. This means messages, that do not conform the structure will be discarded. In addition, only authenticated users can publish data to the connected messaging systems.

Additionally, services can store non-time series data in a MongoDB database. For example, the battery service could hold information about the description, location, and technical details of a battery. This data is available via REST interface of the respective service, for the internal network. The distinction here is due to the different nature of the data. While the data from the field devices is always time related, data within the services is more static and does not have the temporal aspect.

Next to the log data from the field devices, there are other data sources like the weather service, which fetches the latest weather data from external weather services. The weather service stores the weather data into InfluxDB. Interested services can gather the weather information from there. The scheduling service also has external data sources, such as market data with pricing information.

4.4.3.1 Schedule Operator

To be scheduling algorithm agnostic, we have a Schedule Operator that sits in between the devices and the executing algorithm. This service is responsible for aggregating all information about the current system. That includes device data, consumer data with forecasts, environmental data, for example, weather forecasts, and economic data like CO_2-prices or energy market prices and forecasts of them. All these different data are collected via their respective micro-service and then retrieved from the Schedule Operator, which enables interchangeability.

This Schedule Operator service is also responsible for sending the relevant data to the scheduling algorithm in order to start the calculation. After the calculation, the service will also distribute the schedules back to the devices. This could be necessary,

2 Available at: https://github.com/influxdata/telegraf.

3 Available at: https://github.com/influxdata/influxdb.

if for example, the scheduling algorithm has only one abstract heat pump and the real system has multiple. The service will then distribute the load to the different heat pumps. With this abstraction layer, we enable scheduling algorithms to be as abstract as they need to be and still work with the real world system.

As an additional feature, this enables to separate the schedule algorithm into its own service just like the other services. The communication is done via a general interface, in our example we use gRPC[4] because of its platform independence and high performance. This enables the schedule algorithm to be written in any language that has a gRPC implementation. It is also possible to implement another interface, for example RPC via AMQP.

The schedule is usually calculated for a week in advance. To incorporate newer information about the current production and consumption, the operator will prompt a schedule re-calculation every fifteen minutes. Sometimes, the energy system state can change rapidly, wherefore the energy management system has to react quicker. Examples are sudden failures of some energy devices or unforeseen over- or underproduction of the PV devices. If the deviation from the plan is too large for an extended period of time, a premature recalculation will be started. Keep in mind that QEMS is not meant to be used in an island power system, wherefore power stability is never at risk. Hence, short times of a diverging schedule can only reduce the quality of the KPIs values.

4.4.3.2 Scheduling Algorithm

Currently, our QEMS is using a simulation based approach to calculate schedules for the energy system (Agert/Hanke/Schmeling et al. 2020). The Python-based software uses the Oemof framework[5] (Krien/Launer/Schönfeldt et al. 2020) to simulate the energy devices based on the forecasts of energy demand, solar and wind generation, and generates a schedule for seven days in advance. Seven days are used so that the algorithm considers a whole week with the typically differing energy demand on the weekend.

We are working on other scheduling algorithms as well, using the flexible approach. Another approach that is under active development is a local market based approach. The basic idea is that every customer in the district can decide how much local green or local gray electricity is worth it for him- or herself. The prices can be adapted every fifteen minutes, but do not have to. Based on the amount of available local green and gray electricity, the prices and the demand, the scheduling algorithm

4 Available at: https://grpc.io/.

5 Available at: https://github.com/oemof/oemof.

can calculate the schedules for the controllable devices, e.g., the battery and the heatpump.

4.4.4 Device Controlling Services

On the right side of Figure 4.2 are the device specific services that control the devices. They offer high level REST interfaces for other services within QEMS with which the other services can send control signals to the devices or can be used to manually control the devices.

An integral part of this is the management of the devices. The services know which devices are connected to QEMS, know their properties such as peak power and have the information on how to connect to the devices.

The devices typically have a specific way they can be controlled. For example, a Combined Heat and Power Plant (CHP) may offer a Modbus interface with which the device can be turned on and off and can be modulated to a certain degree, meaning that the power output can be changed in a certain range, but not freely. For example, a 5 kW CHP may be able to be run on any power output level between 3 kW and 5 kW, but not below or above. The respective power output can be reached by setting a value on a Modbus interface to a value between 0 and 1. This very device specific knowledge is not implemented into the scheduling service, but in the respective device specific service, here the CHP service. This way, no matter which kind of CHP is used to fulfil the schedule, the schedule service can always use the same interface of the CHP service.

Next to the specific way the single devices are controlled, more device specific knowledge is integrated into the respective services. For example, a heatpump (HP) may not be switched on and off too often in a short period of time. If the schedule contains a sequence where this happens, the HP service will prohibit sending these controls to the device and notifying the schedule operator service about this.

4.4.5 KPI-Service

The key performance indicator (KPI) service calculates the KPI of the district energy system and provides the information to interested parties. To do this, the service subscribes to the relevant topics of the messaging system and uses the messages to continuously evaluate the respective formulas of the KPI. The information is then broadcast to the messaging system, where other services and interested parties are able to subscribe them. While this could be the district operator on internal side, there could also be public services requiring information.

One example would be the energy signal light. As it is a challenge to reach the citizens of the respective district, it is a goal to make it possible to perceive some information about the local energy system in a ubiquitous way. For this purpose, the information from QEMS also feeds an external service controlling the energy signal light, which is depicted in Figure 4.3. The goal is to indicate to the consumers when it is a good time to consume energy to give a load shifting incentive by switching the signal light to red or green. For the signal, we can think about different approaches like the local surplus electricity or the district CO_2 production.

Figure 4.3: Prototype of an energy signal light to be build flush-mounted.

4.4.6 Other Services

There are more services, which play specific roles in QEMS. The weather service collects and prepares weather data for the district to provide it for other services. For example, the energy demand service needs temperature data to forecast the heat demand and the PV forecast needs cloud forecasts to estimate the PV generation.

More services are possible, but currently not implemented. The data from the field devices could, for example, also be used for predictive maintenance calculations to detect necessary maintenance early and schedule downtimes in advance.

4.4.7 Information Interfaces

The information that QEMS provides is relevant for different users and use cases. Hence, QEMS has multiple information interfaces to share the information. Especially, but not exclusively, these information are useful for the grid operator and the district aggregator. In the following sections, some of them are presented.

4.4.7.1 KPI Interface

Public participation and information can be an important part of district energy systems (Brandt/Schäfer/Schmeling et al. 2021). Therefore, QEMS has an interface to share information with interested stakeholders.

Within an energy district, externally managed energy systems, which are not directly controlled, by the energy management system can have a direct impact on the KPIs of the district. For example, a hydrogen production unit consumes a high amount of electricity but can manage at which times it is doing that. For the energy system, it is useful that the hydrogen is produced in times of surplus energy, if possible. Due to the ownership situation, QEMS cannot directly control this system. Nevertheless, QEMS can share information about the state and the forecast of the energy system. Based on this information flow, the hydrogen unit can decide when to produce the hydrogen. It also tries to reach the goals of the energy district, e.g., low carbon emissions and a high self-consumption ratio.

To allow such systems to adapt their behaviour to the energy system, QEMS shares the information as a JavaScript Object Notation (JSON) string. It contains the timestamp for which the data is valid, the name of the district and a number of values for that point in time. Among them are the electricity consumption in the district, the surplus electricity and the current generation in total and from the single generation devices. The current state of the battery and the KPIs are also part of the information object.

Additionally, a time series of these objects is also made available with a forecast of the values. This is meant to ease the scheduling of other systems that live outside of QEMS but can also benefit from the information, for example an externally controlled hydrogen production. The interval and length of the forecast is dependent on the scheduling algorithm.

4.4.7.2 Grafana Web View

The main visual interface is the web view for the district aggregator, who manages the energy system and supervises QEMS. We use a Grafana instance with custom plugins for this purpose. The view has two main user groups: the commercial district aggregator and the technical supervisor.

The commercial district aggregator is mainly interested in the KPIs. Important information for the aggregator is the estimated development of the price, self-consumption ratio, the current schedules, and the CO_2 emissions. Figure 4.4, shows a mock-up of a glyph which aims to show the most important information for the district aggregator at a glimpse. The dark blue bars show the current value of the three KPIs price, CO_2 emissions, and self-consumption ratio. The lighter blue chart above shows the past forecast, so that the user can see the forecast error over time. May the most left point of the chart be the forecast for the current point in time from twelve hours ago. Then, the forecast error for the price was very high at the beginning but reduces to a very close forecast.

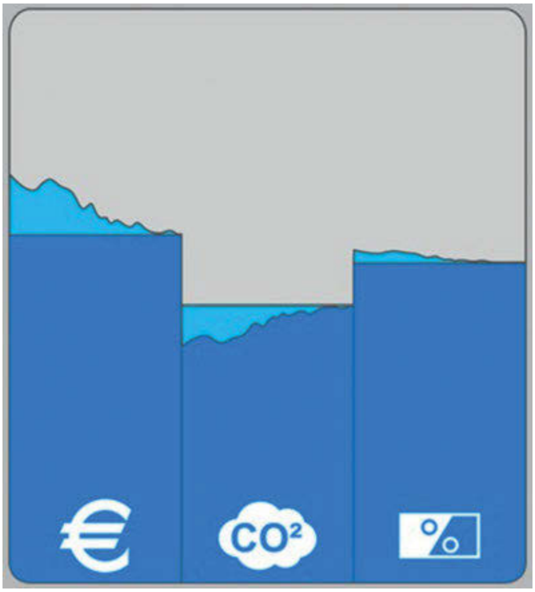

Figure 4.4: A glyph showing the current KPI values and the forecast until now. The forecast error over time can easily be seen by the aggregator.

The technical supervisor is mainly interested in the field device data to see if the devices are running well or to figure out causes for errors. Next to detailed time series data about the state of the devices, QEMS implements a custom plugin to show a system overview in Grafana. Figure 4.5 depicts the energy system of the neighbourhood having a combined heat and power plant (CHP) configuration, as previously planned by the project partners. The colour schema helps to differentiate the electrical and thermal power. Electrical power flows are coloured in green, while the hot water flows are purple and the return flows are light blue.

On the left, the CHP (German: BHKW) is depicted. Currently, it delivers 5 kW on the electrical and 12 kW on the thermal side. The peak load boiler (German: SLK) is switched off and the heat storage tank is filled by 38.7%. The temperatures of four sensors at different heights of the storage tank are shown next to the tank. The state of charge is depicted by the dark grey bar inside of the storage tank.

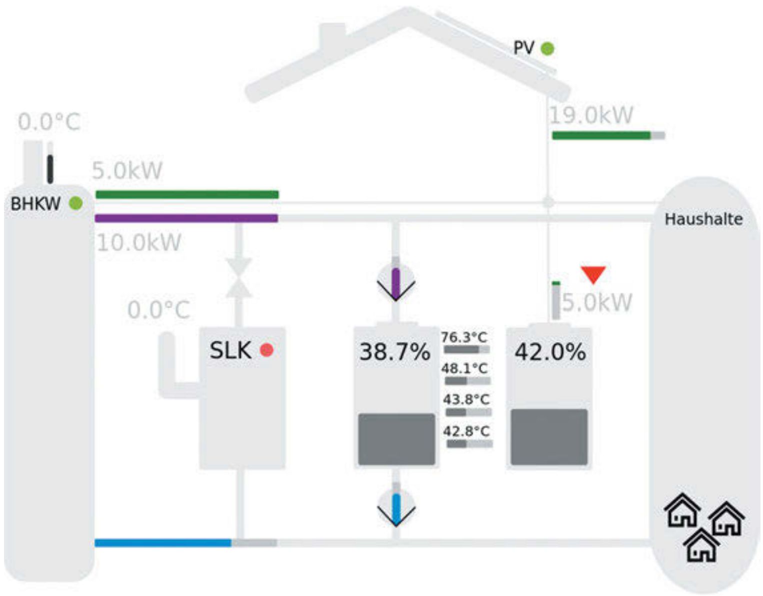

Figure 4.5: Overview of the current field device states. The interface design is based on work in (Herdel/ Wortelen/ Lanezki et al. 2020).

Next to the heat storage tank is the battery, which stores electricity. The arrow above the battery indicates if the battery is currently charged or discharged. The state of charge can be seen inside of the battery symbol. A symbolic roof depicts the PV generation, which is again indicated by a green bar.

The consumption side on the right shows the households (German: Haushalte). The current implementation is not final and needs to be extended. The return flow is not shown right now, as the necessary data sources are not available in our experimental setup yet. The household consumption is also missing. These issues will be part of the coming development in the living lab together with the stakeholders, mainly the users of the user interface.

4.4.8 Summary

In this section, the architecture and software details of QEMS had been described. An architecture overview was given with a description of the single services which work together mainly via messaging systems and REST interfaces. The field communication to the energy devices, such as PV systems and batteries, are realized with two communication channels. On the one hand, a custom communication setup can be used, on the other hand, a system that relies on regulated Smart Meter Gateway (SMGW) connections is described as well. The data management is mainly done with a central time series database and custom databases per service. The scheduling and forecasts are done in specialized services which have a platform independent interface to scheduling and forecasting algorithms. The exchange to users and other systems is done via interfaces, e.g., to share current and forecasted key performance indicators (KPIs), give energy managers a simple to use overview via a web view and allow a ubiquitous and simple information for customers.

4.5 Experimental Setup

QEMS, as described in the previous sections, is currently in active development and is planned to be used in a living lab to control the energy system in a small neighbourhood with about 140 households. In the following, we describe the environments in which QEMS is developed and tested. The living lab is described in Section 20.5.1. Since the neighbourhood is not built yet, we use a smaller test environment that is described in Section 20.5.2.

4.5.1 Living Lab Environment

The QEMS development is embedded in the living lab research project,[6] which has the goal to build a new neighbourhood with about 140~households with an affordable and sustainable energy supply (Brandt/Schäfer/Schmeling et al. 2021). The living lab is located in a newly developed district in the city of Oldenburg, Germany. The neighbourhood is newly build, wherefore ideas from the project can be integrated into the buildings and surrounding area. Next to the housing units, a so-called technology island is planned, where new technologies can be tested. The whole area is equipped with sensors, e.g., for dust, NO_2, CO, and a car counter.

For the living lab, it is currently planned to have photovoltaic (PV) systems, several heatpumps (HP), one for every building, an energy storage system (ESS) for two buildings, and thermal ESS. The power and heat demand for the whole district is monitored in near real-time. Together with the monitoring of the power and heat generation facilities, this data is crucial to calculate the schedules and control the devices accordingly.

QEMS is meant to be running in a cloud environment, controlling the energy devices remotely. For the case of communication errors, a fallback mode is programmed directly into the local devices.

6 Available at: https://www.enaq-fliegerhorst.de.

4.5.2 Test Environment

As the living lab district is still under construction, we use another test environment for the current development. The main part of this environment is a virtual collection of devices, like a combined heat and power plant (CHP), an HP, PV systems and ESS, which are connected to the QEMS environment. These virtual devices mimic their counterparts behaviour and communication to the QEMS. For example, we mimic the Modbus interface of a CHP on a Raspberry Pi connected to the controllable local system (CLS) interface of an smart meter gateway (SMGW) to have a virtual device that can be controlled without real consequences.

The Modbus interface of the virtual as well as the real CHP allow to control the power output of the respective device and retrieve information about the current state, for example the current heat generation. We also enable using uncontrollable devices that send real data, like a PV system installation on the roof of a partner building. The demand of a virtual building is also implemented.

4.6 Conclusion and Future Work

In this paper, the system architecture for a district energy management system called QEMS for a living lab in Germany is shown. The system is targeted for small districts and neighbourhoods that have a shared energy system in which a district aggregator operates and integrates multiple different energy devices, such as PV, ESS, and HP. The goal of the system is to manage the district energy. Key goals here are high district self-consumption of energy, low CO_2 emissions and low energy costs. These goals are collected and distributed to interested parties via message broker.

The architecture of QEMS contains the field communication to the actual energy devices, which can both be done via a custom setup and the regulated SMGW. QEMS itself is build up from small services, each with a certain narrow scope. The device specific services implement detailed knowledge about the connected devices, if necessary, to monitor and control them. The generic services on the other hand are not device specific, but implement control mechanisms for the district, for example, scheduling algorithms, demand forecasting and KPI calculation. The services communicate via a message broker as well as internal REST APIs. The data monitoring data from the devices is stored in a time series database and the users can view the data in a customized Grafana web view.

The main goal for the future work is the implementation of QEMS into the actual living lab to control the devices, deliver energy and optimize the defined KPIs. Beyond that goal, future work could extend the scope to not only view the energy system within the district, but also take part in the low voltage grid management. Due to an increasing electrification of energy usage, e.g., for mobility and heat, the low voltage grid networks can be overloaded during peak times. In cases that a low voltage network management system detects such an overload, it could ask DEMSs that operate energy districts within the network to reduce the consumption or increase the power generation. This way, network shortages can be managed down to small energy devices.

Further research about an active participation of residents into the energy system is of importance. Can low-threshold methods like the aforementioned energy signal light help to shift energy consumption of the residents or can we only rely on more sophisticated methods like a HEMS?

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Oliver Norkus, Jens Wotte, Matthias Brucke

5 Establishing a Smart City Data and Interoperability Platform

Summary: As part of the ENaQ project, a digital platform is being developed and tested with use cases. This digital platform consists of three layers: Citizen's access to the (a) community portal. The community portal uses the services that run in the (b) service platform. The data, especially from the field level, is processed and stored in the (c) Smart City Data and interoperability platform. This chapter sheds light on the Smart City data and Interoperability platform. It will reveal how the platform was conceived and developed, and why standards are important for the development of platforms and services and which ones have been used. This paper provides into the platform technologies and shows some selected use cases for evaluation.

5.1 Introduction

To realize the energy-efficient neighbourhood, an infrastructure concept is being developed and implemented as part of the "ENaQ" project. This integrates the physical infrastructures for the electricity, heat and electromobility sectors supported by the energy couplers into a cross-sector supply network. In addition, the project focuses on the conception and implementation of a digital service platform for intelligent load and procurement management for decentralized energy producers and consumers and for smart city applications at district level. The intention of the digital twin of the physical platform is, to provide the functionality required for the organization and operation of local energy cooperatives, other cooperation models at district level in cooperation with different energy service providers or for a wide range of smart city applications. In addition to technical issues, residents as energy producers and consumers (prosumers) are also involved in a transdisciplinary approach via a community portal. They are involved by the conception of incentive models for the formation of local energy cooperatives and the business models derived from them for the service providers to set up and operate the energetic neighbourhood.

The energetic neighbourhood district as the real laboratory is the initial project with an energy focus, other projects will follow with different focuses, e.g., mobility

Oliver Norkus, is a full professor for business computing at the University of Applied Sciences Bremerhaven
Jens Wotte, works as a senior software engineer for embeteco GmbH & Co. KG. He studies computer science at the University of Oldenburg
Matthias Brucke, is co-founder of embeteco GmbH & Co. KG. He studied Engineering at the University of Applied Sciences in Revensburg-Weingarten

https://doi.org/10.1515/9783110777567-005

or health. In accordance with the Smart City strategy of the city of Oldenburg,[1] this project must also form the basis for the follow-up projects. This also applies to the digital platform, which should not only serve the energy focus, but should also be suitable for other focus areas in the future. Thus, topics as standardization and interoperability are of crucial importance.

The focus is the conception of an open, flexible and at the same time secure digital platform. This includes in particular

- the provision of the necessary flexibility for a wide variety of yet unknown business models and services,
- the consideration of data protection, data security and data sovereignty,
- the design as a scalable cloud-based medium
- as well as the creation of open, standardized interfaces for later integration of other user-related services related to energy or Smart City.

As part of the digital platform, various M2M[2] communication services are integrated via a BSI[3]-compliant smart metering infrastructure and heterogeneous data sources. This enables the integration and control of all necessary field devices in the district and in the households. For this purpose, various modules are designed to implement the Smart Meter Gateway communication infrastructure and the Smart City IoT infrastructure. One of the main modules is the Smart IoT solution which is placed centrally in the Smart City data and interoperability layer of the digital platform. This platform layer is a central component for

- managing and storing the available data (e.g., sensor values like brightness, temperature measured on a smart pole, pressure and fill levels of the hydrogen systems, energy consumption of the households),
- for data-centric operations and analytic (e.g., predictive maintenance of the hydrogen plant) and
- to make all components work together seamlessly (e.g., ensuring a uniform semantic exchange format).

This article focuses on the area Smart IoT solution. Due to the importance of reusability and the extensibility of the platform, the topic of standardization is of great importance here and is first considered in the following section. The project ENaQ is characterized by the fact that many different partners are working on the digital platform. Therefore, a transparent and methodically mature procedure for coordination and concentration was necessary. One of the following sections is dedicated to this topic, but beforehand the relevance of standardization for smart data and interoperability platforms is

1 Available at: https://www.oldenburg.de/startseite/wirtschaft/zukunftsprojekte/smart-city.html.

2 M2M = machine to machine.

3 BSI = Bundesamt für Sicherheit in der Informationstechnik, German Federal Office for Security in Information Technology.

highlighted. This article then goes into the architecture of the IoT solution and concludes with use cases where the feasibility is demonstrated.

5.2 Relevance of Standardization

The Internet of Things (IoT) is currently the subject of many discussions in science, politics, industry and in the private sphere. The IoT will narrow the current gap between the real world and the digital world. In the process, states and things from the real world are increasingly being fed into the digital world to enable further processing of the state information using information technology. The fields of application are diverse: from Smart Building, Smart Living, Smart Home, Smart City and Smart Region to Smart Factory, discussed in the industrial environment under Industry 4.0, but also in relation to the transport and health care system – the thrust of Smart Everything. Ultimately, IoT can affect all areas of human life and activity. This development is accompanied by many changes in communication, organization and management and is seen as a major expansion area in the economy. In the environment, early detection of maintenance needs is discussed, the reduction of power consumption and much more, especially from the point of view of artificial intelligence.

This development and the changes bring challenges with them. Challenges are, for example, the description of data points, the communication of sensor values, the control of actuators, the integration of virtual sensors, the use of the sensor data provided in services, the design of IoT services and platforms. The goal behind the challenges must be interoperability. To achieve interoperability, standards must be developed, driven, and promoted. For example, if smart meter gateways are used for smart city applications, the associated security and interoperability challenges must be addressed. The technical and operational challenges arise from the use of smart meters in various network scenarios such as WAN, HAN and LMN (Local Metrological Network). The safe and comprehensive use of smart meters in various applications (e.g., in smart city silos) in Germany is regulated by the technical guideline BSI TR-03109 developed by BSI. The technical prerequisites and mandatory requirements for functional components of the smart meter gateway ensure interoperability and the secure use of smart meters between the smart city domains. The areas of application addressed by the BSI guidelines are for example smart grids, smart homes, smart buildings, smart charging infrastructure, smart metering and electromobility. The series of measures in the BSI TR-03109 guideline ensure both the technical and organizational (smart metering rollout) course for data protection, data security and interoperability.

5.2.1 Application Domain: Smart City and Smart Region

The activities taking place within the Smart City projects can be divided into three categories. These are operational project planning for the comprehensive digital transformation of cities and regions, the development and consolidation of urban IoT infrastructures and the expansion of new business models for data-supported digital services (e.g., citizen services). This results in new technological challenges in terms of interoperability and data regulation as well as the technological merging of individual smart city silos and the central coordination of silo-spanning operating processes. To be able to develop smart city applications in a sustainable and scalable manner, a comprehensive digital strategy and a holistic technological development framework are required to address four core aspects: digital citizens and citizen-centricity, connected IoT ecosystems (across silos), digital platform services for citizens (G2C), business (G2B) and real-time capable interoperable data platforms. The technological challenges in the development of IoT services for smart cities are essentially the lack of interfaces in the IoT infrastructures and limited data exchange formats. Furthermore, the previous technical standards only support cross-silo data interoperability and service development to a limited extent, since the smart city silos (e.g., transport and energy) are historically based on very different infrastructures and data systems. The possibilities for merging the domain-specific data to develop new services, which should create new added value and system optimization for smart cities and smart regions, are only limited due to either regulatory or data ownership aspects. The legal requirements (e.g., GDPR) bring new regulatory and legal challenges regarding data interoperability, especially for the collection, use and provision of data for the development of new and owner-independent platform services. Many municipalities and authorities are increasingly striving to also offer citizen-centric services for the (local) economy. The technological challenges here are the standardization of portal access and uniform account management for various government services, which must be developed beyond municipal borders in the sense of uniform and secure interfaces. In addition, there is the problem of connecting real-time capable and customary platforms (e.g., B2B transaction platforms) which do not fully meet the complex requirements of the e-government law.

5.2.2 Specific Standards and Norms

The standardization activities for the wide range of technology and strategy aspects of Smart Cities and Smart Regions are diverse and driven both internationally and nationally. The standardization of technologies, processes and data systems contributes significantly to the successful planning, implementation and operationalization of Smart City and Smart Region projects. In Germany, the standardization and corresponding activities for German-speaking regions are primarily organized by DIN and

DKE. These activities are linked to thematic interfaces of the relevant working groups and international activities of ISO, IEC, ITU, CENELEC, CEN and ETSI. The technical division of the German DIN and DKE activities for Smart Cities includes broad technology topics such as mobility, logistics, networked buildings, structural infrastructure, urban processes, digital cities, energy, protection, security, and production. Standardization is of central importance for successful product development in Smart Cities and Smart Regions (e.g., platforms, IoT services and citizen services). The internationally and nationally harmonized standards ensure a technological and domain-specific basis for the interoperability and compatibility of digital services and ICT systems. This basis of interfaces, standards and guidelines contributes to the successful operationalization of Smart City and other IoT projects. The standards define the framework for the conception and continuous development of new data-supported services and processes of digital networking. New digital operating and business models are necessary for both municipal administrations and companies. Standards offer orientation here. The international market for IoT platforms and domain specific IoT services is growing rapidly, and this development is leading to a paradigm shift in value chains and industries. A uniform view of IoT platforms is necessary as the basis for interoperability. For this view, the following layer architecture can be discussed:

- Physical level: control boxes (from e.g., CHP, PV systems, air conditioning systems, etc.), Smart City sensors, actuators, meters (e.g., for electricity, gas) and other devices and data points
- IoT level: operational management, data persistence, CLS management, aggregators, measurement data management, authentication, and authorization
- Service level: portals for end users (in the Smart City context: citizen portals), energy services, maintenance services (e.g., predictive maintenance)

The standardization of guidelines and norms on the one hand and platforms for smart cities and regions on the other hand, as well as for IoT solutions in general, is of central importance by ensuring sustainable value creation and system convergence between IoT domains through proactive standardization activities. Thus, the smart city data and interoperability platform explained in this paper, follows the standards in the relevant field which is mainly the DIN SPEC 91357.

DIN SPEC 91357 describes the structure of an open data platform for public space. The goal of an open urban data platform is to provide municipal decision-makers, companies, organizations, and citizens with trustworthy access to public data for the joint use and design of municipal and private-sector processes. In the future, modern municipalities will increasingly see themselves as service providers for citizens and companies. The availability of open data and, if necessary, its marketing should support this. Open data is understood to mean both commercial and public data on urban infrastructures, resources, traffic volumes, air quality, etc. Aggregated information is also included, and citizens and businesses can actively participate in providing and using the data and information. Special focus is placed on the reuse of the data and information. However, a precondition for the implementation of this guideline and the actual use of open data is a data platform based on non-proprietary solutions that grants various service providers (public and private) non-discriminatory access to this infrastructure.[4]

The specification, developed in a consortium of cities and industry representatives, describes the reference architecture, and sharpens it with generic main usage scenarios, design principles and a glossary. The specification provides municipalities with a framework, forms the basis for further exchange and is to be brought to one of the international smart city groups.[5]

5.3 Methodical Approach: Conception in a Complex Partner Structure

As discussed previously, due to the high relevance of standardization specially to gain an overall interoperability the whole conception of the digital platform follows the DIN SPEC 91357. Thus, the architectural approach is aligned with the reference architecture model open urban platform with an integrated data exchange and interoperability. Nevertheless, the concrete technically designs of the digital platform, where the IoT Platform is a layer of, needs a specific methodical approach to deal with the various partners involved.

To specify the system landscape and the associated derivation of necessary software modules and interactions between the modules, different functionalities were modelled as event process chains (EPCs). They represent the applications or use cases of the system landscape.

The EPC diagrams are intended to depict the technical requirements for functionalities, e.g., end-to-end data transmission between two systems. Technical support systems that may also be required, such as FTP servers, should not be shown in the EPC.

The EPCs and the overall system landscape derived from them serve the consortium as a means of coordination among themselves, i. e. they are intended to be a tool for cross-partner coordination. Initially, they do not serve to ensure that different employees of the same consortium partner coordinate with each other within their organization. This means that the EPCs and the system landscape should have a corresponding level of abstraction.

Within the service platform and the IoT platform, for example, there are further internal components for different purposes with different interfaces to each other. However, these components should not be shown since they are initially only relevant for the respective manufacturer of the platform and not for outsiders.

4 DIN e. V. (publ.) (2017): “Technologie und Mensch in der Kommune von morgen – Impulspapier zu Normen und Standards – SMART City“, Berlin.
5 Ibid.

This is to ensure that the overall system landscape, as the highest level of overall abstraction, remains clear for all various partners.

Of course, the components within one of the main components such as the service platform or the IoT platform are detailed in separated figures. They then serve as a means of coordination between the employees of a consortium partner or, if necessary, between different consortium partners.

Considering the methodological approach with the EPC diagrams, they show which actors (systems and people or organizations) are involved and which data is to be transferred between which actors. The corresponding systems and their required interface connections to each other can be represented in a logical overall system landscape (see Figure 5.1: Architectural overview), which corresponds to a derivation from the EPC.

5.4 Architectural Approach

Looking from the top, the digital platform consists of the modules community portal, service platform, IoT platform and an authentication and authorization system, each of which is subject to architectural principles in the overall system landscape following the reference architecture DIN SPEC 91357. With these architectural principles, the respective modules take on specific tasks that the other modules do not take on. The community portal specializes in taking over interaction with users both via web interfaces and app interfaces. Similarly, the IoT platform specializes in taking over the communication and storage of corresponding data from various end devices that contain sensors and actuators.

The service platform specializes in executing the core business logic, which may involve both user interaction and/or device interaction. All three modules can hold independent databases required for their purposes. These must be linked together in a suitable way, which must be provided by the service platform.

Figure 5.1: Architectural overview shows the IoT platform's architecture in an unfolded layer view. The upmost and the lowest layer contain adjacent systems, which aren't part of the IoT platform. One exception is the *Leitwarte.*[6] It implements a frontend for the IoT platform to manage connected devices and provide further analysis features.

All components from the client layer require access to the IoT platform. "Schulz Telemetry" is a gateway for IoT devices without the capability to connect to the internet on their own. The service platform is a container for various services and acts as an intermediary for the community portal, while the *Leitwarte* allows technical users to connect directly to the platform. However, both the frontend and the service platform are forced to use the API manager as a gateway to the platform. It holds a definition of all the IoT platform's API endpoints together with a list of scopes for these endpoints. This manager

6 A "Leitwarte" (German) is a kind of a digital Control Room.

will authenticate and authorize incoming HTTP REST requests[7] by validating the client's JSON Web Token[8] (JWT) and verifying that necessary scopes are present.

The network proxy layer routes all incoming connections to internal components and terminates SSL encryption, since all platform layers are part of the same cluster network.

The interface layer is the only layer that contains components which provide APIs to external components. The platform API implements a HTTP API to manage the entities inside the platform. Contrary to this, the platform adapters provide access for devices and device gateways by implementing various protocols.

Alongside the first three layers is the authentication component implemented by the Azure Active Directory B2C.[9]It is an independent third-party component, which is responsible for creating and holding user accounts and creating, signing, and validating JWTs. Components like the service platform and the Leitwarte need to request JWTs from the AD before making a request to the API manager. The API manager will forward or reject these tokens, depending on the validation and the scopes contained therein.

If requests are forwarded to the platform's API, it will again validate the tokens to make sure that it wasn't manipulated. This process concerns user authentication. The device authentication process relies on internal components, in which their owner configures their access through the frontend.

Internally there are generic services and a message broker. The latter receives IoT data through the platform adapters and provides it to other internal services. The other services implement various features to store, manage and analyse data. The tenant as well as the device service manage meta data of tenants and devices. Actual IoT data will be given to the measurement service. Each of these have their own database. In this way the separation of concerns should be preserved. Other services might not need a database, but if they do, they will also get their own instance.

One peculiarity is that the rule engine as opposed to other internal services, has access to external services. It is restricted to outgoing connections only and on the one hand will gather data for further analysis from external sources and on the other hand it will send commands to field devices. It's also possible to stream data to virtual devices directly since the internal services can communicate with each other.

5.5 Use Cases

One use case of the IoT platform is the integration of the ≪Smarte Pfosten≫[10] project (Smart Pole/Post). In this project, regular street lights are upgraded so that they're

7 Available at: https://datatracker.ietf.org/doc/html/rfc7231#section-4.

8 Available at: https://www.rfc-editor.org/rfc/rfc7519.html.

9 Available at: https://docs.microsoft.com/en-us/azure/active-directory-b2c/overview.

10 The "Smarte Pfosten" (German) is a Smart Pole. Available at: https://smartepfosten.de/.

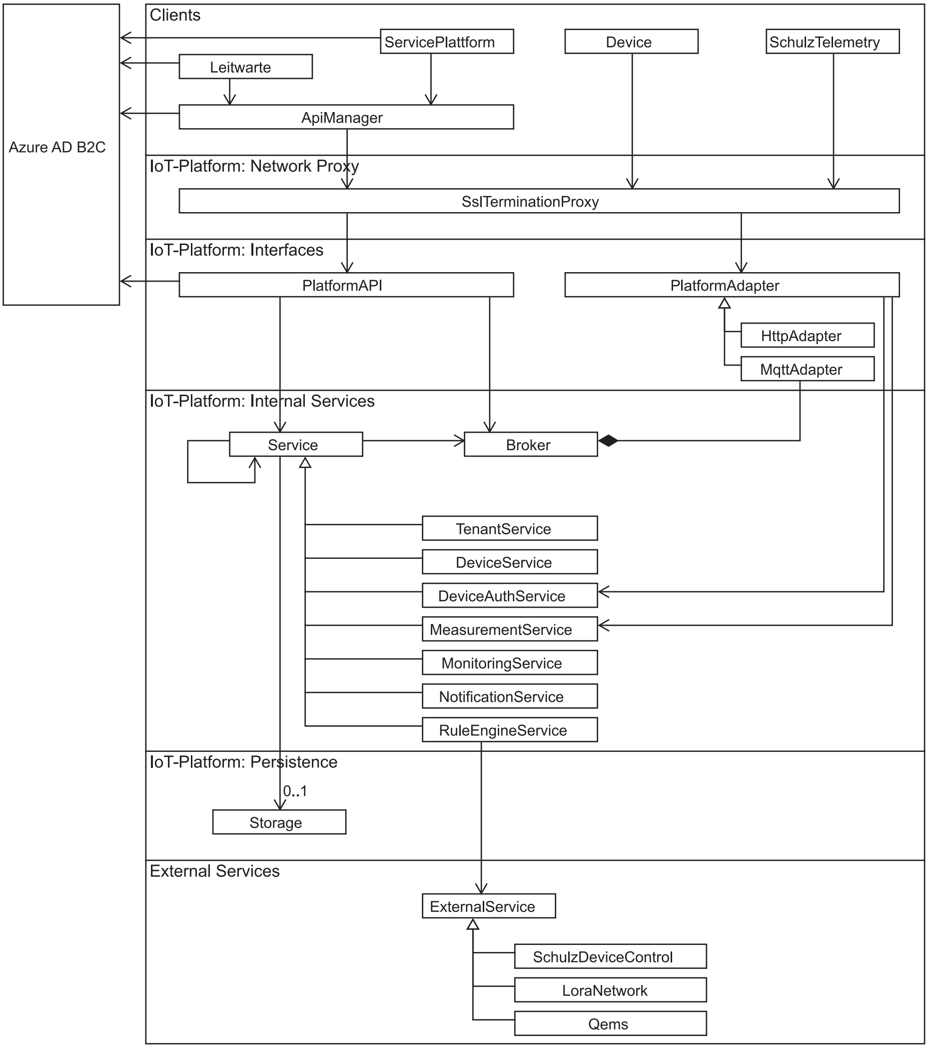

Figure 5.1: Architectural overview.

able to measure various values such as illuminance and fine particles. Each pole is connected to the Policon Communication board, which is installed in the distribution box and enables a connection to cloud services like the IoT platform. Additionally, the upgraded streetlights can toggle installed relays and therefore control the light and other connected devices.

Figure 5.2: Use Cases shows a rough and reduced overview of implemented use cases of the IoT platform. The depicted features enable the implementation of the Smarte Pfosten project. A device on the right side represents a streetlight and can con-

nect to the IoT platform to send measurements of attached sensors. Furthermore, it can subscribe messages to receive switching commands.

On the other side are the users. An engineer who upgrades and manages the streetlights, can be considered a device owner or device administrator. This type of user will login into the Leitwarte to manage the devices. Each real streetlight has a virtual representation in the backend of the platform, which can be created and managed through the frontend application. These virtual devices can then be used to create rules for the rule engine or the notification service. The rule engine helps the administrator to automate data transformation and evaluation processes. By using the notification service, he can receive notification of critical measurements or error messages from his devices.

One of the core features of the platform is to provide the measurements of the devices to the users. In the fronted the administrator can visualize measurements. He can either choose to render raw or aggregated data for further analysis.

The measurements run through an input process before the platform can provide them. Figure 5.3: Sequence diagram push measurement shows this process in a simplified manner. The device connects to one of the platform adapters. In this case it is an asynchronous adapter, which means that the connection will be established beforehand and kept alive independent of the messages.

When a device decides to publish its measurements, it will send an asynchronous message to the adapter. Then follows a chain of operations in the adapter. First it needs to check the access permissions, which are cached during the connection establishment. Secondly it will validate the schema of the payload with a JSON schema definition (data format description for JSON data[11]).

Finally, the timestamp will be unified. This allows devices to send timestamps in different formats e.g., ISO and Unix timestamps) without causing errors inside the platform.

If this is done without errors the measurements will go to the platform broker and ultimately to the measurement service and the rule engine. The former is responsible for storing the data in a time series database. The latter might use it for rules, that were created by the admin beforehand.

A user can use the frontend to create rules for the rule engine. These involve logical and mathematical operations. Once there is a rule, which uses a certain data point as an input, and the corresponding measurement is pushed to the rule engine, it processes the data as defined. After processing it the rule engine creates an output in form of a notification, a measurement of a virtual device or a command for a field device. In the last case the rule engine can either connect to known gateways for device control or publish the new data to the broker. The broker will push it to the MQTT adapter, where a device can subscribe messages for certain topics.

11 Available at: https://json-schema.org.

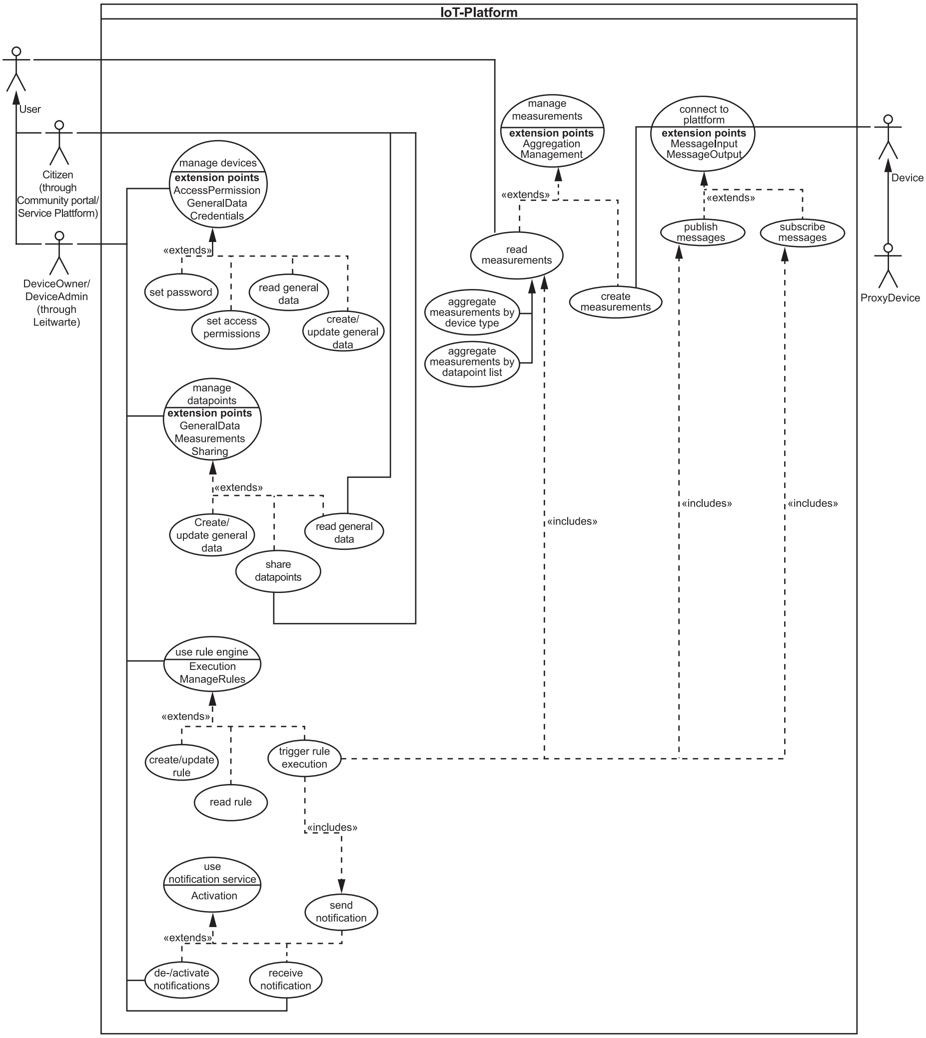

Figure 5.2: Use Cases.

After measurements have been send to the platform. A user can visualise and analyse them in the frontend. For this the frontend needs to communicate with platform API. This process is shown in Figure 5.4: Sequence diagram measurement output. Assume the user is already logged in and the frontend already got a valid token from the external authentication and authorization system.

The frontend caches a list of tenants, of which the user is a member, and devices the user has access to. Requested entities will be filtered in the backend to avoid unauthorized access. To request measurements a user selects one of the data points of a certain device and sets various parameters. Together with the token the formed re-

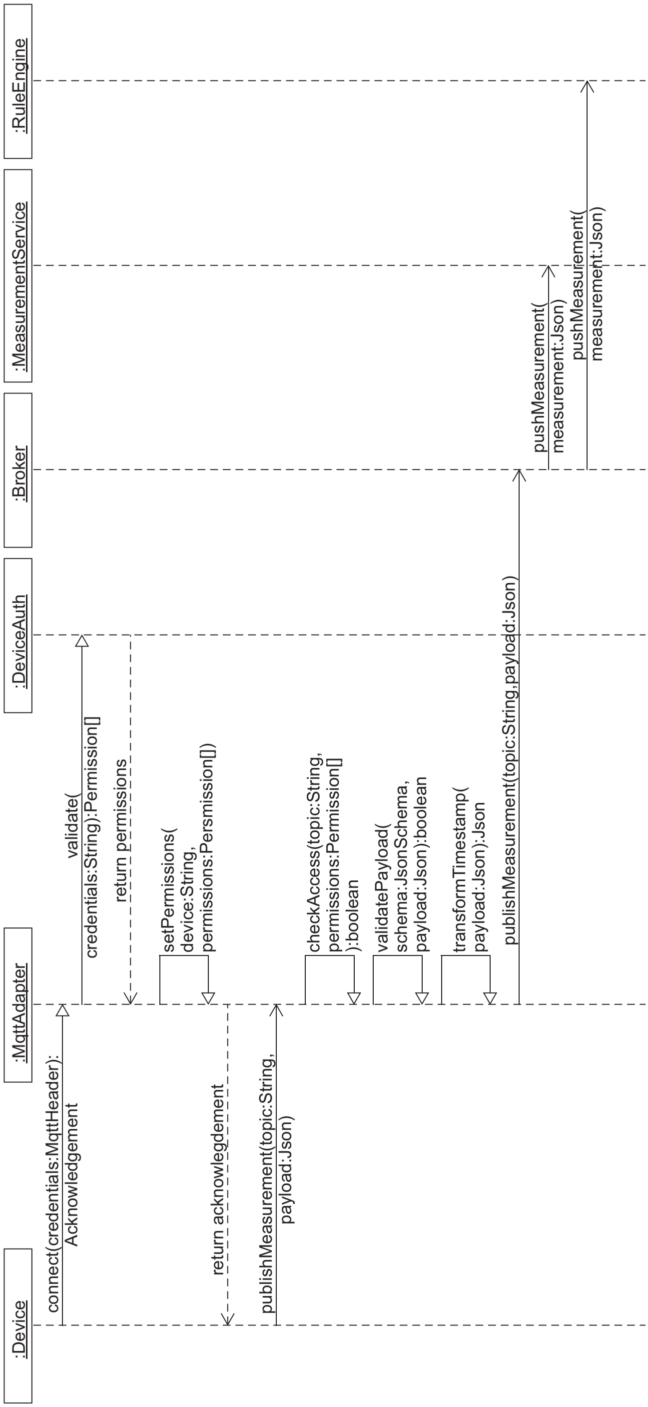

Figure 5.3: Sequence diagram push measurement.

quest will be send to the API. The API checks the access permission for the user and eventually requests aggregated data from the measurement API.

The Leitwarte can render the aggregated data in different ways as Figure 5.5: Leitwarte Screenshot shows. The frontend application provides different ways of visualizing IoT data. The image shows the dashboard page, which can combine different types of visualisations. The purpose of the dashboard is to provide an overview of different data sources personalized for every user. Other subpages implement features to manage devices, for more detailed analysis and to create automated rules.

5.6 Conclusion

As part of the ongoing ENaQ project a digital platform is developed by various partners with three main layers. As the article describes an ongoing project, the Smart City and Interoperability layers were discussed in their actual status. Due to the diverse partner structure the methodical approach with EPC diagrams was choosen – with this in the project were gained good experiences. The architecture of the Smart IoT solution was discussed using an UML component model. The platform is characterized by its modular structure, so the modules can be deployed and scaled individually. The procedure for evaluating the platform is use case driven. Demonstrating the technical breakthrough, the use cases were implemented across all layers. Next to unit tests, system and integration tests were performed. The feasibility of the architecture and the implementation was evaluated by the successful application iteratively around the use cases. In the running project, the platform will be extended especially in Smart City functionality and more data analytics capabilities. With every extension and adaption, it is important to comply with the standards to ensure transferability and technical and professional interoperability.

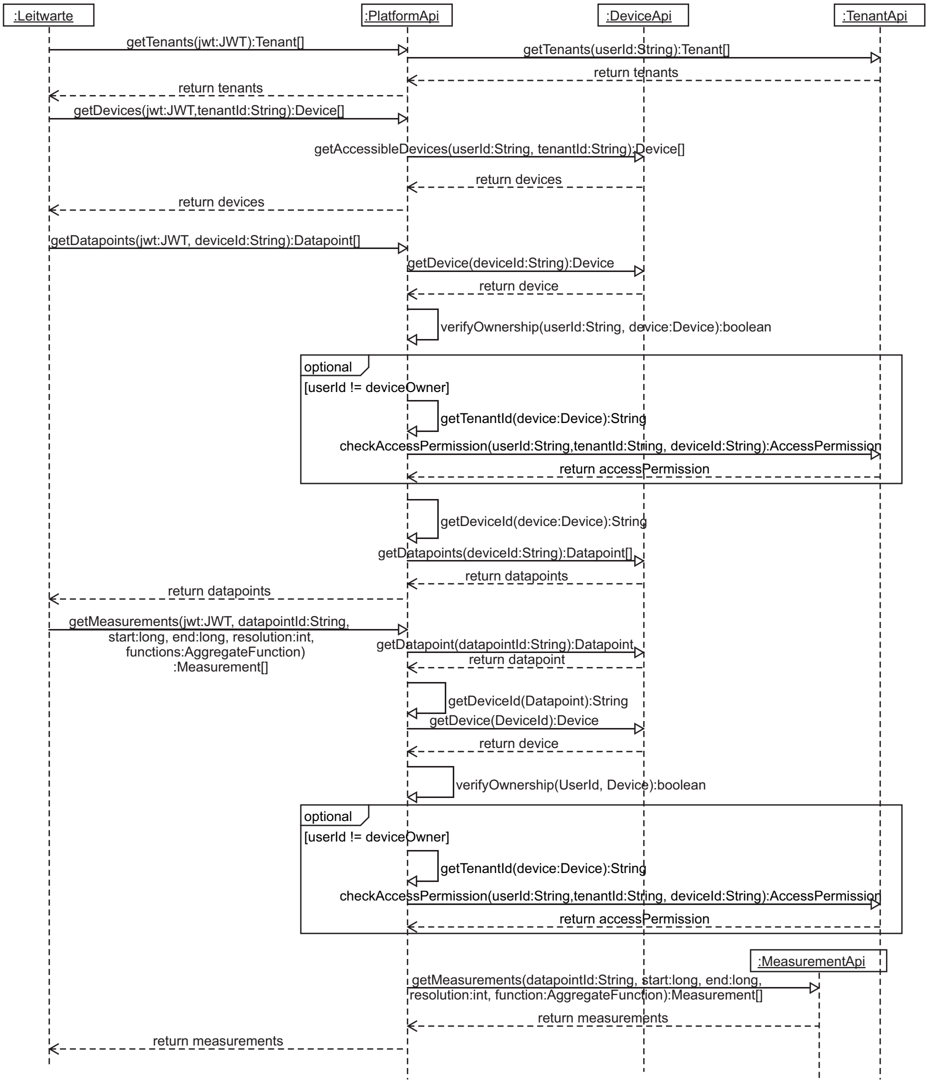

Figure 5.4: Sequence diagram measurement output.

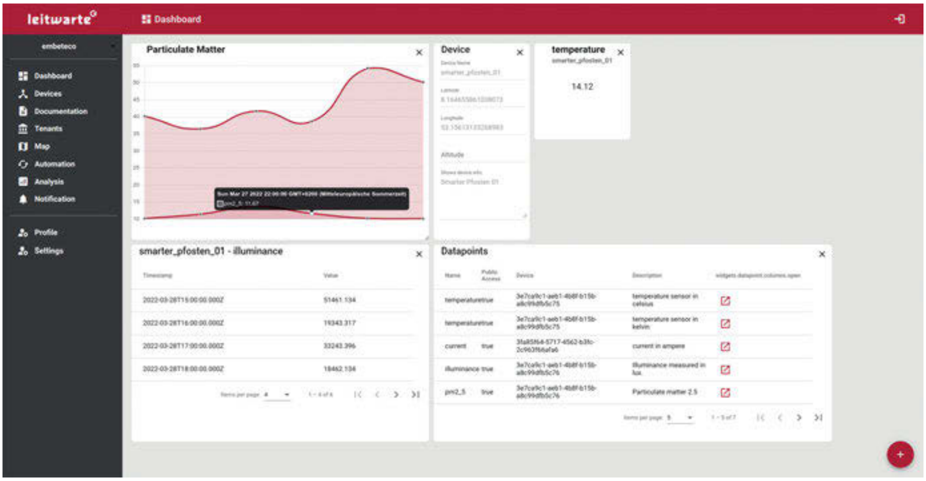

Figure 5.5: Leitwarte Screenshot.

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Maren Wesselow, Torsten Grothmann, Bernd Siebenhüner,
Ulrich Scheele, Ernst Schäfer

6 The Role of Citizen Participation in Developing a New Energetically Efficient Quarter – Limitations and Success Factors

Summary: Citizen participation is vital in the design and implementation of new technologies. In the ENaQ project, a long-term participatory process is applied to accompany the development of a new energetically efficient residential quarter in the city of Oldenburg. This chapter shows how different participatory formats were used to involve the public at different stages of the project. We shed light on limitations to citizen participation in the context of technological developments in the housing sector including the fact that future residents are not known, the highly technical topics, limitations set by external framework conditions, conflicting interests and contact restrictions due to the Covid-19 pandemic. To share our learnings with similar projects, we examine how these hurdles can be overcome, and identify the following success factors supporting effective participatory processes: (1) thorough participation in an early stage, (2) the presence of planners and decision-makers at participation processes, (3) combining technological and social benefits, and (4) the institutionalisation of participation.

Acknowledgements: A large range of organisations and people have been involved in organizing and maintaining the participatory process on the Fliegerhorst area in Oldenburg. Among them are the municipality of Oldenburg, the Institute for participatory design (IPG) and Machleidt planning office planning office, and the housing association GSG Oldenburg. We owe sincere thanks to Stefanie Brinkmann-Gerdes, Theresa Richter, Antonieta Alcorta de Bronstein, Tatjana Timoschenko, Alexandra Unger, Theresa Michel, Burghard Flieger, Georg Blum, Elisabeth Jacobs, Julia Masurkewitz-Möller, Ulrike Brendel, Anna-Lena Sauer, Friederike Hackmann, Mathias Lanezki, Steffen Wehkamp, and Sven Rosinger. We also greatly acknowledge the engagement of many citizens who participated in diverse formats and thus helped shape the development of the new quarter.

Maren Wesselow, Torsten Grothmann, Bernd Siebenhüner, Ecological Economics, Faculty II, Carl von Ossietzky University of Oldenburg, Ammerländer Heerstrasse 114–118, 26129 Oldenburg, Germany
Ulrich Scheele, Ernst Schäfer, The Regional Planning and Environmental Research Group (ARSU)

https://doi.org/10.1515/9783110777567-006

6.1 Citizen Participation in the Context of Technological Development in the Housing Sector

In the context of climate change mitigation, energy efficiency in the housing sector has gained urgency in the last years. Combined with growing demand and increasing property prices as it is the case in Germany, housing and building represent highly debated and emotionally charged topics for many people. High expectations are tied to new technologies as facilitators for an energy transition in the housing sector. In this context, the concept of "Smart Cities" bears potential to contribute to higher energy-efficiency in the housing sector and thus has attracted considerable attention in the context of urban development policies (Moser/Wendel/Carabias-Hütter 2014, Hollands 2015). The concept refers to the strategic approach to the sustainable development of cities that aims at high living standards through an efficient management of natural resources, citizen participation and involvement through the use of ICT (Gagliardi/Schina/Sarcinella 2017). Smart Cities come with both technological and societal developments that are closely intertwined (Schaffers/Komminos/Pallot et al. 2011, Baltac 2019). Besides potential advantages such as more efficiency, better access to information and direct governance possibilities (Lee/Lee/Phaal 2013), some scholars criticise the potential of adverse effects of ICTs such as rebound effects (Viitanen/Kingston 2014), a strong focus on business oriented urban development (De Jong/Joss/Schraven 2015) and the neglect of questions of wellbeing and social justice (Hollands 2008). These risks underline how important it is that technological innovations should be based on the actual needs of the users and should not generate any further needs and should not be developed as an end in themselves. Moreover, it must be kept in mind that despite their focus on digital solutions, smart cities represent physical social spaces with a high potential for direct and not only virtual social interaction (De Jong/Joss/Schraven 2015). Technological innovations, especially in the field of housing, are therefore inseparably linked to social questions of equality, health and the quality of life calling for complementary institutional arrangements such as legal rules and standards (Weiss/Eikemo 2017, Grossmann 2019).

In view of this complementarity of human-technology systems, the inclusion of societal actors is seen as crucial for smart city projects (Gagliardi/Schina/Sarcinella 2017). One form of including societal actors is citizen participation. Citizen particiption can be defined as "the practice of consulting and involving members of the public in the agenda-setting, decision-making, and policy-forming activities of the organization or institutions responsible for such functions" (Rowe/Marsh/Frewer 2004, p. 89). In the ENaQ project, our approach to citizen participation goes beyond traditional "one-way" education and outreach efforts and involves "two-way" interaction with citizens (Powell/Colin 2009) reaching different intensities from information to co-production (Brandt/Schmeling/AlcortadeBronstein et al. 2021):

- Information: One-way communication by offering information to participants, with only little opportunity for participants to comment and contribute to the discussion
- Consultation: One-way communication by questioning the participants, contributions are integrated in the decision-making process
- Co-Creation: Participants are offered specific opportunities for planning and designing solutions and results, the decision-making process lies with the organisers and initiators of such processes
- Co-Production: Participants are involved in decision-making, implementation and possibly the operation of solutions or they organise and initiate the realisation themselves

Many scholars have investigated both institutional frameworks and design principles that facilitate participatory processes. Knipp/Linder/Haubner 2020 (pp.28–29) identified the following success factors of participation processes in the context of municipal sustainability management: early information on the goals and content of the plan, methods to actively approach people, local presence and openness to citizens' ideas, a consistent and clear presentation of the framework conditions, and the willingness to compromises and room for manoeuvre. In addtition, the continued participation at least until the realisation of the project, working with multipliers to reach diverse target groups, and an "enabling" attitude on the part of the administration are quoted by the authors as success factors for participatory processes (Knipp/Linder/Haubner 2020).

As additional determinants of effective participation, Yang/Pandey (2011) identified elected official support and transformational leadership, whereas red tape and hierarchical authority are found to be major hurdles for effective participation. In the context of technological innovation, a further challenge arises from the fact that specific knowledge is required to take sound and responsible decisions on technological innovations such as ICT and energy systems. That is why processes of public participation in transdisciplinary research often tend to be restricted to particular questions, posed at particular stages in the cycle of research, development and exploitation of new technologies, and neglect the deeper questions about values, visions and vested interests that motivate scientific endeavour (Wilsdon/Willis 2004). In particular, the use of participation in later stages of the technological development bears the risk of an instrumental use as "technologies of legitimation" (Harrison/Mort 1998, p. 61 ff.). Yang/Pandey (2011) highlight the complex relationships between success factors for participation outcomes. They found that success factors may be not equally important, they may affect each other, and they may not influence outcomes in a direct way (Yang/Pandey 2011).

Based on these insights, we seek to analyse the experiences with citizen participation in the development of a new smart quarter in the city of Oldenburg. This chapter thus asks which forms and processes of participation took place in the ENaQ project and which success factors or hindrances could be identified. After presenting the long-term participatory process in sub-chapter 6.2, we identify limitations to and success factors for achieving the participation goals (sub-chapter 6.3). In our conclusions we develop recommendations for practitioners and scholars to design effective participatory formats in urban development and technological innovation processes.

6.2 Participatory Development of the Fliegerhorst Area and Helleheide Quarter in Oldenburg

In this chapter we present the long-term participatory process that was conducted to develop a former military air base (the "Fliegerhorst Oldenburg"). The process started in 2015 and is still on-going. It can be divided into three phases (see Table 6.1).

6.2.1 Early Citizen and Stakeholder Participation

Due to its former use as a military air base, the Fliegerhorst area was not accessible to the public for a long time. After the end of its military use, various suggestions for subsequent use were under discussion until the municipality took the decision to involve citizens in the planning and the subsequent development of the area. The involvement of citizens in the development of the Fliegerhorst area started in 2015, three years be-

Table 6.1: Phases of citizen participation in the Fliegerhorst development.

Phase and Intention	Formats	Topics
2015–2016: **Early citizen and stakeholder participation** Engagement of citizens and representatives of different interest groups to design guiding principles and masterplan	– Bike and walking tours on the area – Exhibition on the history of the "Fliegerhorst" area – Idea cards sent to random citizens – "Stadtwerkstatt" (City Workshop) – "Innovation camps"	General values, wishes, preferences first spatial divisions
Since 2018: **ENaQ project: Opening participation processes on specific topics**	– Public events for information, discussion and co-design, e.g. Dialogue forum, Dialogue Days, summer festival	Specific topics: energy system, mobility, ICT
Since 2020: **Institutionalisation of citizen participation** forming a stable group of interested dwellers to meet on regular basis	– Citizen Workshop" on monthly basis, using interactive methods and materials	Neighbourhood and community areas, green areas

fore the ENaQ project. This initial participatory process was co-funded by the German Federal Ministry for Education and Research and the Ministry for the Environment, Nature Conservation, Building and Nuclear Safety and coordinated by the municipality of Oldenburg. The addressees of the participation process were selected stakeholder groups such as local firms and citizens of the city of Oldenburg with different social groups (especially young and low-income groups) to be involved. To raise public attention, the municipal city planners opened up an exhibition in the former guard building of the air base, where interested citizens could inform themselves about the history of the military use of the Fliegerhorst. They also organised public bike tours across the Fliegerhorst area starting in April 2015. In the first bike tour, together with the mayor, 700 residents of Oldenburg took part (Stadt Oldenburg 2015, p. 4). In addition, the planning bureau of the city of Oldenburg sent out 1200 so-called idea cards to a randomly selected sample of citizens asking for their ideas and suggestions on how the area should be developed. 450 cards arrived back at the municipality containing approximately 1300 suggestions (Stadt Oldenburg 2015, p. 329). The responses indicated which topics were important to the citizens –predominantly mentioned were cross-generational, socially mixed, intercultural and inclusive forms of housing. People also called for have opportunities to meet and voiced the desire to design a "green quarter" with opportunities for recreation, sport, playgrounds and nature conservation (Stadt Oldenburg 2015, p. 32). To discuss the development with a higher intensity of participation, a participatory event called "City Workshop" ("Stadtwerkstatt") was organised in June 2015 (Stadt Oldenburg 2015, p. 54 ff.).

In order to address the topics from different perspectives, three different groups of actors were involved: (1) pupils as the generation of potential future users; (2) representatives of more than thirty organisations and interest groups as well as experts, who provided perspectives and expertise from various professional background; (3) randomly selected and invited citizens (Stadt Oldenburg 2015, p. 57).

As a result, ten guiding principles for the development of the area were developed together with the participants. These guiding principles included "diversity in social structure and building culture", "resilient and sustainable quarter", "human-centred approach to mobility" among others. Furthermore, the resulting documentation also mentions the idea of a decentralized energy supply from renewable energy sources (Stadt Oldenburg 2015, p. 51). The organising institute described this participatory process as open and focussed on the development of a new future-oriented residential quarter.

In the next step, the municipality of Oldenburg sought to develop a first masterplan for the area. A professional planning office was hired to lead this process and develop a masterplan in a participatory manner. This plan should implement the general principles and it should detail the spatial division and land uses. In November 2015 and February 2016, two consecutive "Innovation Camps" took place. Based on different model plans, citizens were invited to collaborate on specific topics of the final masterplan. In these events, participants discussed topics such as mobility, water management, energy, sustainability and community life. Half a year later in August 2016, the City Council of Oldenburg unanimously adopted the final version of the masterplan as a basis for the further development of the quarter. It included the goal that the new quarter should be carbon-neutral and that an experimental “Smart City Lab” should be developed in the area (Stadt Oldenburg 2016, p. 79).

6.2.2 The EnaQ Project: Designing Topic-Specific Participation Processes

Simultaneously to the participatory process to develop the masterplan of the “Fliegerhorst”, the municipality of Oldenburg commissioned the development of a smart city strategy. Since the beginning of 2016, this strategy was systematically developed in cooperation with relevant administrative units and regional businesses as well as scientific institutions (Damm/Lehnhoff/ Masurkewitz-Möller et al. 2017).

Following a call by the Federal Ministries for the Economy (BMWi) and for Education and Research (BMBF) in 2017, a consortium of 21 local organisations from public administration, science and the private sector came together to prepare a common project proposal following up to both developments, the masterplan and the smart city strategy. The respective funding call on “Solar construction/Energy efficient City” specified the thematic focus on promoting energy efficiency in the building sector. After the successful application phase, the research and development project “ENaQ” (Energetic neighbourhood quarter) was launched. The project pursued the objective to develop an energy-efficient and smart energy system in one sub-part of the Fliegerhorst, with a digital service platform for intelligent load and procurement management in its centre. While the masterplan referred to an area of 190 ha, the ENaQ project and its following activities only addressed a relatively small sub-area of the Fliegerhorst (3,9 ha). This sub-area comprises 240 residential units with 25% of the units as rental apartments for single households (students), 25% as rental apartments within a social housing framework, and 50% of the apartments being sold on the real estate market.

To design and implement technologies that are tailored to human needs, citizen participation played a crucial role for the ENaQ project. Besides the development of energy technologies and the establishment of a supporting digital infrastructure, citizen participation forms one of the three pillars of the project. In the beginning of the ENaQ project in 2018, the project partners developed a comprehensive participation concept with the following goals for the participation process (Blum/Brendel/Alcorta-deBronstein et al. 2019):

- researching and collecting the wishes, ideas, needs and ideas of the citizens,
- meeting diverse needs and preferences (citizens, administration, experts),
- establishing a political culture of citizen participation,
- providing opportunities for citizens to actively influence the development,

- creating acceptance/legitimacy for the further planning process, and
- advertising for the air base as a future-oriented living quarter.

These motivations epitomise a mixed approach, including normative, substantive and instrumental rationales (Fiorino 1989). The concept detailed the following main topics for the participation: (1) energy trading, digital services, incentivisation, business models, (2) energy cooperatives, (3) the community portal and (4) mobility (Blum/Brendel/AlcortadeBronstein et al. 2019, p. 29). This focus shows a strong emphasis on technological (IT and energy) questions. In the course of the project, diverse formats for participation and information have been implemented to address these topics. For example, in the "Dialogforum Fliegerhorst" in the year 2019 most of these topics were addressed and discussed with citizens. However, due to the the COVID-19 pandemic, they could not be further deepened in participation formats in the following years. While the predominant topics in the beginning ranged around the energy system and IT innovations, less technical topics such as neighbourhood development and the design of green areas entered the agenda in later stages. The topic of water management and climate change adaptation is part of the planning, but the responsible water supply and wastewater disposal company decided against participating as a project partner.

In the summer of 2019, the municipality of Oldenburg and the city's housing association "GSG" organised an idea competition to find a suitable name for the smart city quarter. Over 60 name suggestions were received, and the name "Quartier Helleheide" was chosen by a jury.

In September 2019, the large public event "Dialogforum Fliegerhorst" took place in Oldenburg with workshops on energy and mobility, complemented by a "fair of possibilities". While this event was a joint activity of the project consortium offering a high participation intensity, single project partners launched series of events with more informational character and different target groups. Moreover, project members developed and invited participants to a board game called "Changing the Game – Neighbourhood" (Lanezki/Siemer/Wehkamp 2020). Within this game, the players take on the role of project managers who can design a neighbourhood according to their own standards. Using various materials, the players can build up their neighbourhood in order to achieve the climate goals.

When the Covid-19 pandemic commanded contact restrictions in 2020, participatory methods had to be reduced to online formats such as surveys and online workshops. Nevertheless, so-called "Dialogue Days" could be organised by the project consortium in 2020. They included a series of events such as an online-broadcast discussion round on what good neighbourhoods look like. In addition, walking tours in the quarter (with 150 participants in total), as well as a public board gaming session were organised. Additional formats included online events prepared by students from the University of Oldenburg who developed and organised specific complementary participatory formats on the topics "sustainable mobility" and the development of an

"Energy Signal Light" (Brandt/Schmeling/AlcortadeBronstein et al. 2021, Klement/Brandt/Schmeling 2022). Moreover, a three-day workshop on long-term consolidation of community structures in sustainable residential quarters was held at a students' conference in June 2021.

Since a large range of stakeholders formed part of the project consortium, it is important to mention that internal participation among project partners played an important role within the ENaQ project, for example on the development of novel business models and an energy cooperative.

Despite the ongoing contact restrictions, a summer festival was hosted on the Helleheide area in August 2021 to raise public attention. The two-day event included different thematic tents with project partners presenting their own innovations and demonstrators (e.g. hydrogen car). One booth invited citizens to model future climate neutral cities by using Lego bricks. The entire event attracted about 150 participants. Yet, it can be assumed that the pandemic situation and the hygiene regulations have prevented some interested actors from active participation.

6.2.3 Institutionalisation of Citizen Participation

The participatory formats were covered in social and public media channels and received a high level of public interest in the city. At the time, more and more people approached the project consortium with the interest to purchase or rent apartments in the Helleheide quarter. In response, the housing company brought together a stable group of participants and one facilitating project partner in 2020 in novel and more continuous participatory format. The "Citizen Workshop" ("Bürger*innen-Werkstatt") convened on a monthly basis to discuss concrete questions concerning the future neighbourhood. The mailing list is open to any citizen with interest in the project and more than 90 people have registered. However, only about 20 people (most of them with interest in living in the area) regularly participated in the meetings. In the early phase of the format, discussions revolved around the planning and design of the buildings, so that suggestions could be included in the actual plans. Further topics were public spaces surrounding the houses, mobility and communication in the neighbourhood as well as creating a vivid community life. In this format, varying experts from different thematic areas addressed by the project, such as architects or engineers were present to explain the actual state of planning or the functioning of a certain technology. This also ensured that the citizens' opinions were included into further planning and decision making. However, this format had to be shifted to a digital version when contact restrictions were put in place.

6.3 Limitations to and Success Factors for Citizen Participation

During this long-term process, the project team experienced that citizen participation faces many hurdles and limitations. Nevertheless, we could also identify factors that foster the success of the participatory processes. The limitations and success factors outlined below refer to the goals of the participation process as defined in the participation concept. We aim to assess the hurdles and remedies for achieving these goals and thus draw conclusions and recommendations for other participation processes.

6.3.1 Limitations to Citizen Participation

6.3.1.1 Difficulties in Reaching Different Target Groups

A first major challenge for the participatory processes was the fact that the future residents of the quarter were yet unknown and, thus, could not be targeted directly by the participatory formats. What is more, the construction of the buildings was delayed several times during the course of the project. The housing association defined target groups for the apartments in terms of household size and prize (e.g., low-income households, students for single apartments, some apartments for families), so that participatory formats should address a mixed target group. The project's approach was to reach different groups of citizens through a variety of different formats on different topics, that communicated via different channels and at different locations. However, many participants involved in the various participatory formats were not future tenants or house owners in the area so that the results of the participatory processes might be biased by individuals with other interests than the residents.

The Citizen Workshop as a regular format constitutes a chance to target especially those people with a specific interest in living in the new quarter. The evaluation of the Citizen Workshop confirmed that most participants of the meeting were interested in moving to the Fliegerhorst or the Helleheide quarter. Interestingly, most of the active participants in the Citizen Workshop can be categorised as elderly (above 60), which might be explained by the fact that these people avail of sufficient time resources to participate in this regular format.

Especially marginalised groups such as people with low income or education, and people who do not speak German as well as people with scarce time resources (such as juveniles and families) could hardly be reached by the participatory activities. To reach people with little time resources, an official leave to free them from their school, university or work obligations could be an incentive to participate. Moreover, a childcare service during participation events could encourage more families to take part in the events. In order to target marginalized groups, participation that approaches people in their everyday environment, e.g., when shopping or at festivals, could be a strategy. This type of participation also presupposes the openness of researchers to unconventional solutions and labour-intensive formats. This strategy was considered in the ENaQ project, but could not be carried out due to the COVID-19 pandemic as this type of participation requires an immediate and direct exchange. Other low-threshold participation approaches rely on the use of visualisations, habtic materials and playful approaches as partially applied in the ENaQ project.

Although many engaged and active citizens took part in the formats, our experience shows that there are also citizens who see themselves as “passive consumers”. They would like to be informed about relevant developments (which affect them), but they are not interested in the systems in the background. It was considered as a task of the project to provide information to them and to keep the opportunities for a higher level of participation open.

To deal with this challenge that future residents are not known, some ENaQ partners implemented parallel participatory formats and pilot runs in an already established neighbourhood in Oldenburg with similar characteristics to the Helleheide quarter. The quarter Neu-Donnerschwee comprises an area of 18 ha based on a former barracks site. Since 2016, new buildings were built and old buildings were renovated in an energy-efficient way. Today, it is a residential area with social infrastructure (e.g. kindergarten, playground, bus connection) and open spaces. The quarter residents have formed a dedicated community aiming to be diverse, family-friendly and inclusive. This connection between Neu-Donnerschwee and Helleheide is not only a way to link the new quarter to existing similar projects in the city, but also provides opportunities for mutual learning and exchange.

6.3.1.2 Highly Technical Topics Requiring Extensive Prior Knowledge or Extensive Educational Efforts

Whereas the themes of the early participation process touched upon many topics of spatial development and social life, the ENaQ project focussed on the development of a quarter energy system combined with different ICT platforms. Many of the projects’ topics concern high-tech solutions of new and intelligent renewable power systems that are not visible and difficult to understand for users. For example, the digital platform through which the communication with sensors and controllable devices is managed will not be visible to the users. Nevertheless, the highly complex decisions related to these solutions come with implications for the future residents of the quarter. Hence, to discuss technological topics with citizens, knowledge on these topics is required and it is difficult to convey it in a short time during a workshop. This requires large informational and educational efforts, which must be taken into account when budgeting time and financial resources for participation. Alternatively, complex issues need to be boiled down to fairly simple questions and topics that are easier to understand but would leave out specific aspects.

Participatory events need to be designed in correspondence with the differing degrees of technical competence of the target groups. It is therefore particularly important to know the target groups of the participatory events and their prior knowledge on the topic. As it was not always clear, which audiences were reached and attracted by event invitations, tailoring the events for the participants needs was difficult in the ENaQ project. The Citizen Workshop gave the organisers a chance to get to know the participants better and design the methodologies accordingly. In this way it could be assured that the events were facilitated in a competent, citizen-friendly and sensitive way and that activating and interactive methods were used. For example, participants worked with layout plans and materials such as lego bricks which helped them to understand the physical dimensions of the buildings.

6.3.1.3 External Conditions

Although the design of the energy and ICT system of a new quarter offers room for participation, some limitations are defined by framework conditions such as the project proposal or the budget. Additional external requirements are set by natural, technological, juridical and financial structures. In the context of the ENaQ project, especially legal conditions played a predominant role. It turned out that the regulatory framework for numerous technological issues (especially in the energy sector) was often unclear, contradictory or very complex. In consequence, it was made sure that relevant actors such as decision-makers and planners were present in the participatory formats so that they could intervene directly when the suggestions became unrealistic. Another factor that may have influenced the participation process is the fact that there was still no physical place on the Fliegerhorst site itself where people could meet continuously and exchange ideas or work together on ideas. This circumstance might have driven the project to be perceived as somewhat intangible, unspecific and remote from the public.

6.3.1.4 Conflicting Interests and Mismatch of Expectations

While participatory processes generally seek to include a large variety of viewpoints and interests by multiple stakeholders, it is impossible to meet all demands that are raised. At moments when concrete development decisions have to be taken, a number of alternative ideas and opinions must inevitably be ignored or given second priority. We experienced that some participants of the early participation process got frustrated when they learned that not all of their ideas and suggestions were realised. Conflicting interests and a mismatch of expectations render participatory development a delicate venture, especially as the topics of housing and energy supply might be emotional to many people. For example, the discussion about a bypass road which the municipality plans to build to release the existing feeder road of the Fliegerhorst raised a controversial debate. Since this new road will lead through an ecologically valuable biotope, a public debate and considerable resistance to this project has developed in the city of Oldenburg. This resistance is understandable insofar as the new construction of the street runs counter to the concept of a "sustainable" quarter. However, the current feeder road is already at its capacity limit, so that the construction of the new road seems unavoidable from a city planning perspective. The discussion reveals that, for often pragmatic or economic reasons, not all expectations can be met.

Nevertheless, Helleheide quarter is planned as a largely car-poor area. Compared to other residential areas, it provides a low key of parking spaces (0.6 parking spaces/ per residential unit) so that not every household can have a car and offers a neighborhood garage as common parking place. With the aim to increase the quality of life in the quarter, the streets within the district were declared as pedestrian zones. The outdoor space will therefore not be occupied by parking cars, but can be used for neighborhood meeting places, the garden and nature.

Although all ENaQ partners have agreed on the goal of sustainable development of the district, each has a very different view of the project. Industrial partners associate different economic interests and expectations with the project, while research partners pursue their own research agendas. Consequently, the interests and expectations of the participatory process are heterogeneous and not always evident. Overall, it is noticeable that there are few voices within the project that represent social concerns and needs. This underscores the need to acknowledge citizens as important stakeholders of the project.

6.3.1.5 Contact Restrictions due to the Covid-19 Pandemic

The contact restrictions due to the Covid-19 pandemic posed another great challenge to the project. The restrictions that were effective between 2020 and 2022 with phases of differing rigor prevented the organisation of larger physical meetings. Consequently, participatory methodologies that involved in-person meetings were not operable anymore and citizen participation was mainly limited to online workshops and surveys. These processes led to reduced possibilities of intensive co-design, conflict mediation and negotiation of interests on the one hand. On the other hand, the emergency situation encouraged the digitalisation process and led to the shift of social life to the digital area. Some participatory formats could take place online, these were complemented by online surveys. Additionally, a digital platform was set up where people could raise comments and contributions, and commented and supplemented other people's ideas (https://werkstatt.enaq-fliegerhorst.de/#/start). Despite these efforts, it must be assumed, that these online formats excluded social groups which lack of resources, knowledge or interest in internet-based communication, thus exacerbating the digital divide.

6.3.2 Success Factors for Citizen Participation

6.3.2.1 Thorough Participation in an Early Stage to Set a Normative Basis

The extensive discussion and participation process that preceded the ENaQ project opened the doors for the subsequent development of the Helleheide quarter. A large range of citizens were involved in developing the guiding principles that set a common value base for the further development. When more technical questions were addressed in the later phases of the process, they were grounded on the normative basis to form a climate-friendly, affordable and socially diverse new quarter. The process also contributed to the generally high public interest in and support of the ENaQ project. Hence, many citizens follow the developments closely or are interested in living on the site. This also led to relatively high expectations and it is still questionable whether these can be met at the end of the project.

6.3.2.2 Planners and Decision-Makers are Present at Participation Processes

One feature of most participatory formats was that planners and decision-makers were present and participated in the discussion. On the one hand, they shared their knowledge and doubts with other participants. On the other hand, they listened to the ideas and concerns raised by the citizens. It was to the great advantage of the project that many important stakeholders formed part of the project. In this way developers and decision-makers not only received budget for the participatory approach, but were also bound to participate in project activities and information exchange. Thus, the housing association as owner of the area and buildings as well of the municipality of Oldenburg were very engaged and supporting project partners. Both the municipality and the housing association pursued the goal of creating a new quarter that is geared to the needs of the residents, valued the importance of citizen participation and took on the active role in organising citizen participation formats. The project benefitted from this "enabling" attitude.

6.3.2.3 Combine Technological and Social Benefits Offered in a Residential Quarter

The great public interest in the project is not only due to the housing shortage, but also due to the expected advantages and amenities of the life in the Helleheide quarter. In particular, the aim to form a socially mixed community attracts potential residents. The early participation process showed that people value a vivid community life, opportunities for leisure activities and green spaces that offer recreation. Although the ENaQ project had a technical focus, it was important to open the range of participation topics in this regard. The discussions in the Citizen Workshop revealed that technological innovations turned out to play a minor role to many of the (elderly) participants. Instead, they suggested physical communication through pinboards and shared activities. Therefore, the fact that the quarter is not only perceived as a technical and impersonal space is very important. The process also showed that technologies cannot be considered in separation from the people who use them. Even if people are not intrinsically inclined to adopt technological innovations, social incentives may be a channel to reach them and open the discussion on the advantages of technological solutions. Through participatory formats, participants could also get in touch with more technological topics such as “Energy Signal Lights” (that show consumers at which time energy should best be consumed), energy cooperatives and small photovoltaic systems on the balconies. In this way, synergies between the social and technological developments can be exploited.

6.3.2.4 Institutionalisation allows Higher Intensity of participation

In the early phase of participation, interested citizens raised the desire to remain transparently informed about further developments. Others lost interest after the first events and never returned. In order to do justice to these different interests, participation formats with different intensities were offered. A fixed format (the Citizen Workshop) was introduced so that committed addressees could be involved continuously and intensively in the discussions. The format offers the opportunity for close collaboration between developers and citizens. For example, the arrangement and equipment of the community rooms could be adopted to the wishes and needs of the participants. In consequence, two community rooms that are apt for different purposes (e.g. a laundry café) will be realised in the Helleheide quarter. In general, the regular format of the Citizen Workshop was very well received, as is allows intense collaboration on equal footing and empowers citizens to engage in complex discussions to make informed decisions. This was also confirmed by an evaluation questionnaire filled in by the participants. Nonetheless, different levels of interest are also reflected in this format, with some citizens regularly taking part in meetings, while others only remain silent readers of the minutes of the meetings and newsletters. It also needs to be highlighted that this time-intensive format hardly reaches people with scarce time resources.

6.4 Conclusions and Outlook

The contribution presents a long-term participatory process from laying the normative foundation to the negotiation of detailed questions. This holistic view showcases the diversity of not only technological but also social questions raised along the development of smart city projects. Generally, our results confirm many of the supporting factors for the success of participation processes in the context of municipal sustainability management listed by Knipp/Lidner/Haubner (2020, see above). By identifying and analysing some specific limitations and success factors, we contribute to a more complex perspective that recognises the specific difficulties and ambivalences linked to participatory processes in smart city development.

We underline that citizen participation in the context of technological development in the housing sector should be an ongoing process, although high importance lies on the participation in the early stages of the project (before the development takes place). Laying the foundation for the further planning and development of the "Fliegerhorst", the early participatory processes were pivotal to involve broader audiences and to ensure support for the resulting master plan. In these early stages, the normative basis for the future development is laid and common objectives can be determined. As the interests of citizens differ, it is important to offer participatory formats with differing intensities. However, the goal to reach different target groups (especially marginalised groups) remains a challenge. The fact that decisions on technological solutions require openness and detailed technical knowledge puts a major hurdle to citizen participation processes. Nevertheless, it has to be acknowledged that for residents, quarters are predominantly physical spaces with recreational, social and aesthetic functions. Consequently, it is important to open the discussion to topics that exceed the technological focus of the project. Ideally, technological and social benefits can be combined in a synergetic way. One of ENaQ's strength is the development of a stable group of interested citizens who meet on a monthly basis. This format enables intense collaboration and empowerment through regular and close contact between planners and users. Moreover, the relation to an already existing quarter with similar characteristics is of great value, since it facilitates mutual learning and exchange. Despite these assets, the fact that the ENaQ project is linked to high expectations remains a challenge. Diverse interests and claims on the future development will inevitably lead to frustrations among certain participants and project partners as the development evolves. At the current stage, the buildings are not yet concluded and dwellers have not yet moved in. Thus, the question whether all raised ideas can be implemented and if the quarter lives up to these expectations cannot be answered yet.

Furthermore, it remains questionable how the quarter and the community will develop after the ENaQ project ends in 2023. It will certainly be a critical step to hand over the responsibility to the community to fill the quarter with life. The municipality of Oldenburg is planning to set up a permanent service point for different experimental projects in the urban development context as well as a Smart City advisory board. Moreover, the municipality of Oldenburg made the decision to achieve climate neutrality by 2035. This ambitious objective is likely to intensify the debate about the design of new residential quarters beyond the Fliegerhorst area and Helleheide quarter and will certainly also give new impetus to the establishment of fixed participation structures. We are confident that many of our experiences can be transferred to other new or existing quarters and intend to assess the transferability of the participatory processes in detail until the end of the project.

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Stefan Büscher, Silke Lorenz

7 “Mixed Reality Systems in the Participation in Urban Land Use Planning.”

Summary: Public participation in urban land use planning is often confronted with the problem that these people are sometimes unable to interpret plans correctly. Even through consultations the misunderstandings arise and after implementation the problems are recognized and criticized. Therefor it has to found a better representation to help the public to visualize the object on the plan correctly. The newer visualization Mixed Reality could help in this regard. This article investigates these technologies in relation to be used for land use plans and development plans. As an example, the following analyses will show, if Microsoft HoloLens glasses can support the planning process from a practical point of view.

7.1 Introduction

In urban land use planning, public participation nowadays usually takes place through explanatory presentations of the planning documents in the committees designated for this purpose. At the same time, the documents, which are usually two-dimensional plans, a text section and some explanatory three-dimensional sketches, can be viewed on the homepage of the local authority. This type of participation favours those parts of society that can read and understand plans and can imagine the implementation of the planned projects on site. Experience shows that this can only be compensated to a limited extent by advisory assistance.

New visualisation technologies offer the possibility of integrating those persons into urban land use planning that have been excluded by the formerly procedures practised so far. In addition, these can reduce the errors that could result from the mental reconstruction of the objects of the plan (Wietzel 2007).

7.2 Participation in Urban Land Use Planning

In order to gain a better insight into the advantages of using new visualisation technologies, the following is a brief description of how urban land use planning is legally defined.

Stefan Büscher, Jade Hochschule
Silke Lorenz, Jade Hochschule

https://doi.org/10.1515/9783110777567-007

The land use plan is prepared by the community or the city as a preparatory plan. This plan covers the administrative area and determines where which land use is planned. A land use plan is officially binding (see § 5 BauGB).

A development plan deals with the areas to be developed on a smaller scale. It specifies how the individual plots of land are to be built on. This includes, among other things, the maximum height and area of the buildings, the roof shape and colour, and the design of the facade (see §§ 8–9 BauGB).

A procedural flow regarding the participation of the two plans is similar. After a planning impulse and the first plan concept have been created, the population and the public interest groups are involved in the process at an early stage. After evaluation and consideration, the plan is revised. If there are no significant changes, it is decided to publish the plan. The public will be informed of the period of the exhibition through the usual channels, such as the daily newspaper. During the period of one month, the current draft of the plan is displayed and gives citizens the opportunity to inspect it and to comment on it in writing. The comments are collected, evaluated and weighed up (see § 3 II BauGB). After revision, the plan is to be submitted to the local or city council. After the council's decision, the land use plan is submitted to the next higher administrative authority for approval (see § 6 I BauGB). If this is approved, the plan is published in the official journal and can come into force after that. The development plan, on the other hand, does not require the step of approval by the higher administrative authority.

7.3 Model Visualisation Options

The possibilities for displaying digital objects are constantly evolving. In addition to displaying them on a computer screen or presenting them on a wall using a beamer, there are more immersive visualisation methods. These are briefly described below.

7.3.1 Virtual Reality

One type of model visualisation is virtual reality. Here, the user is in a digital world, whereby the virtual stimuli of the real world are faded out. Head-mounted displays are usually used for this purpose, which are stretched in front of the individual eyes like a screen (Grimm 2013). One example for the kind of display are seen at Figure 7.1. The stereoscopic display in front of the eyes creates the impression of spatial depth.

Figure 7.1: HTC Vive.
(Source: Available at: https://www.vive.com/de/
(Accessed: 14 April 2022)

7.3.2 Augmented Reality

Another method does not hide reality, but extends it. Augmented reality creates additional information on digital images of reality that is available to the user. Common methods of augmented reality are smartphone applications that display reality on their screen through the built-in camera and blend the additional information on top of it (Kästner 2021). Figure 7.2 shows the SiteVison software, which can accurately overlay augmented reality models on reality with the support of a GPS receiver coupled with a smartphone.

Figure 7.2: Trimble SiteVision.
(Source: Available at: https://sitevision.trimble.com (Accessed: 14 April 2022)

7.3.3 Mixed Reality

The augmented reality method forms the basis for mixed reality. Here, the objects displayed are not just static additional information tied to a specific location, but can be manipulated by the user. The user can move, rotate or scale the displayed model in space and the model remains in the position in space in which the user left it. The reality can be seen through the lenses of the glasses. The additional objects are projected stereoscopically onto the individual glasses. The glasses calculate the exact positions in the lenses for the models to be displayed by recording the environment with several built-in cameras (Broll 2013). For this purpose, “Optical See Through” devices are used, which are similar to glasses. One of the best-known mixed reality glasses are the HoloLens from Microsoft an is seen at Figure 7.3.

Figure 7.3: Microsoft HoloLens 2.
(Source: https://www.microsoft.com/de-de/
(Accessed: 14 April 2022)

7.4 The Way to the 3D Coordination Model on the HoloLens

The challenge for cheating a 3D coordination model is to merge different specialist models, such as building and infrastructure models, together in a digital environment. The number of useful interfaces for Building Information Modeling (BIM) based building objects and Geographical Information System (GIS) based infrastructure elements are very low. One possibility is an Industry Foundation Classes (IFC) model, presenting the Helleheide residential area as an example. The focus was to find a best-practice method for using the full potential of HoloLens visualisation.

The modelling is mainly realised by using some applications of the company Autodesk. Revit is used for the building constructions. With respective AutoCAD add-on modules from third-party manufacturers, it is possible to design and construct the specialist models of the infrastructure. Desite md (thinkproject) provides the functional platform for merging all objects.

To generate the example model, the GSG (Gemeinnützige Siedlungsgesellschaft Oldenburg GmbH) provides a Filmbox (FBX) file. FBX is a data format often used in 3D visualisations and animations. This file is converted into the common CAD format DWG for further processing. Out of this, the necessary building dimensions and facades can be transferred into a Revit model. After the model has been created, each building receives a BIM-standardised IFC output. In order to add the missing georeferencing, the position of the models is detected with the help of the site plans. The plans for road construction and drainage are provided by the local water board (OOWV) as PDF files.

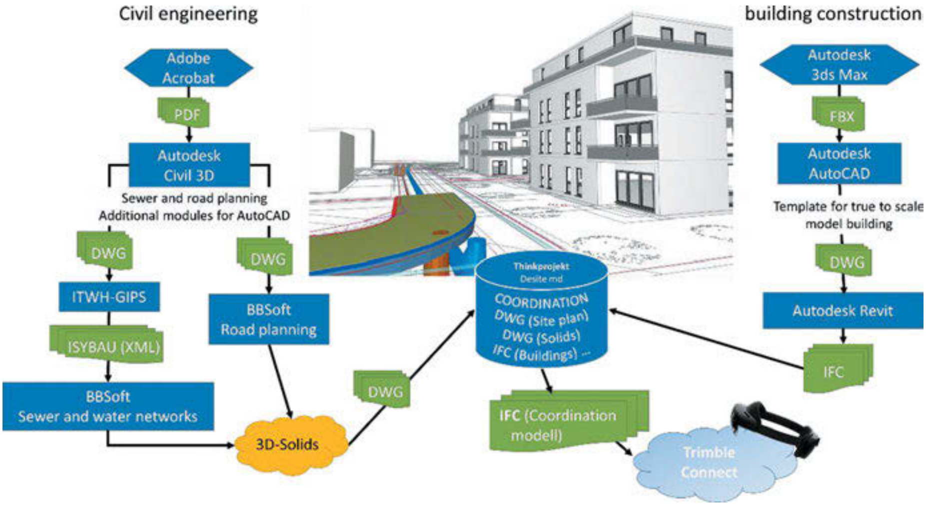

Figure 7.4: Illustration of the model development.

These can also be used as a CAD basis by vectorising them. With the use of additional software for sewer planning and road construction (GIPS from itwh, BBSoft), the infrastructure elements are generated and the sewer data are saved in a database. After all, the elements can be output as 3D solids. The result are geometry objects in standardised CAD format without any component information and database connection.

At the end it is possible to create the coordination model (Figure 7.4) using Desite mb (thinkproject). The previous created models can be imported there. In Addition to that many other formats can be integrated. The result of this merging is one or more IFC-files. After uploading the IFC overall model to the cloud-based platform Trimble Connect, the model can be made visible via the HoloLens.

7.5 Analysis of the Feasibility of Model Visualisation

In order to find a suitable procedure and the appropriate technology for integration into the participation process in urban land use planning, important requirements must first be defined that are to be fulfilled or would be desirable. The following criteria are not exhaustive (Table 7.1). They only cover some basic criteria that are necessary or desirable for such a visualisation. It is assumed that the model visualisation takes place in a building as part of the presentation. During or after that, it is possible for interested persons to view the model.

Once the requirements are defined, the respective technology must be analysed to see how much it can fulfil the requirements. This analysis focuses on the visualisation possibilities of Mixed Reality, especially the work with the Microsoft

Table 7.1: Criteria catalogue for model visualisation.

Criteria	Explanation
Multi-User visualisation	It must be possible for all interested persons to have the same experience with the model (Wietzel 2007). Therefore, it is necessary that the model is available on several devices or that a user change requires minimal effort and that no changes take place in the process.
Intuitive handling	It must be easy for non-technical users to understand the functions after they have received an overall explanation. A time-consuming individual briefing would go beyond the time frame of the event. This is the only way to allow all persons to examine the model on an equal level.
Model positioning	The model must be visualised in a practical place for the user within the building. The positioning should not change after a change of user. It is desirable that the model can also be fitted in the place of use.
Simple model generation	In the process of creating the planning documents, it is necessary to create models. If this has already happened, then at least an interface needs to be found for the visualisation software.
Low financial investment	Besides the additional working time, there are costs for hardware and software. These costs can recur annually. The whole costs should be kept as low as possible.
Level of detail	The method should allow a low and a high level of detail. For some observations, only shape and size are relevant, others may require explicit facade visualisation. Depending on the focus of the visualisation, the level of detail should be selectable (Wietzel 2007).

HoloLens2 and the tested software Trimble Connect. This software a cloud-based BIM platform for collaboration on construction projects. The observations on the individual requirements are shown below. The land use plan is not intended for a three-dimensional view, which makes an analysis for mixed reality visualisation irrelevant (Wietzel 2007).

7.5.1 Multi-User Visualisation

The representation of the hologram is only visible to the user of the glasses. This creates three possible solutions for the community, but none of them is perfect one. When using several pairs of glasses, a model project can be loaded by a host user and joined as a collaborative project in the other glasses. However, this requires the licence of Trimble Connect for each of the spectacles individually. This would have a significant negative impact on the costs in point 7.5.5 Another possible solution is to stream the model image from the glasses to a screen, but this is not provided by the software used. This generates only a few extra costs, but the persons are no longer treated equally as long as not everyone receives the possibility to use the glasses.

Therefore, there is no big advantage of this method. The third option is to use glasses that are continuously passed around the event. This is the most time-consuming way, as everyone does the viewing individually.

7.5.2 Intuitive Handling

Once a model has been positioned in the room, the operation is easy to understand for the inexperienced user. The model is operated by a hand gesture that represents the joining of the outstretched thumb and index finger. With this gesture, the model can be touched and moved, seen at Figure 7.5 on the left. If both hands using the gesture to touch the model, it is possible to create a rotation or a scaling by moving the hands in relation to each other, seen at Figure 7.5 on the right. With these functions and the fact that the user can move in reality, it is possible to examine the model properly because the model remains in place without interaction. It is important to note that in very bright lighting conditions, such as sunlight, gestures are not easily detected by the system. If the visualisation is scaled to real size, the control by gestures is no longer available and the user can only move through the model.

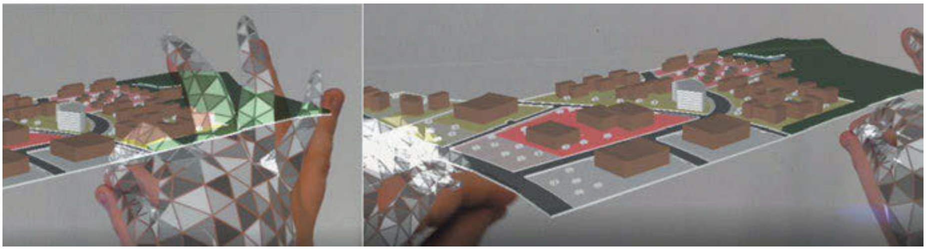

Figure 7.5: Gesture of Trimble Connect.

7.5.3 Level of Detail

The Trimble Connect software allows huge amounts of data in the model, but starts filtering out elements very at an early stage to ensure a smooth visualisation of the model. This means that either the size of the areas being represented in the model must be very small, or the parts of the model must be made of very simple objects with very little detail. In addition, the colours have a different effect when viewed through the HoloLens. This is caused by the fact that the colour contrast is not scaled or cannot be scaled to counter the external light influences on the eyes. Therefore, dark objects can appear almost monotonously textured in the visualisation, while the model itself has a complex texture. This problem was already mentioned in 2013 in the article by Broll (Broll 2013).

7.5.4 Simple Model Generation

For the required digitisation step from plans to software readable model, there is no suitable automation method. You can see in Chapter 7.4, that with the variety of the required planning documents of the many disciplines and the usage of many software products the generation of the model is very slow and need a lot of handwork. For the simplified creation of the models for the area Helleheide one person need about 25 hours. This shows, that the model generation is one big area of improvement.

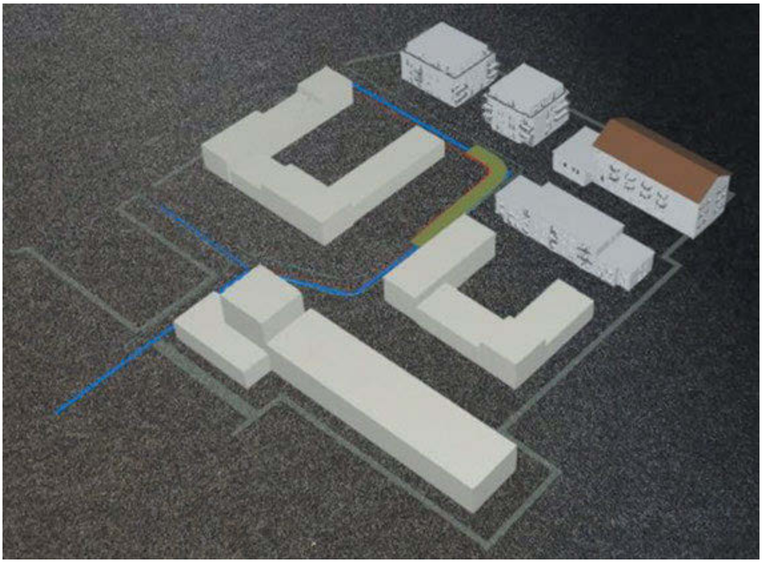

Figure 7.6: Reduced visualisation of the model.

7.5.5 Low Financial Investment

The cost of a pair of glasses is just under 4.000€ (Microsoft Corporation 2022). In addition to the hardware, the cost of a Trimble Connect licence is 2000€ per year. This license is required to walk through the models at scale, as shown in Figure 7.7, or to enter into a collaborative project. If only the small holographic visualisation in Figure 7.6 is needed, it is possible to use the free version of the Trimble Connect application.

7.5.6 Model Positioning

The positioning of the small hologram can be implemented quickly. To do this, it is placed on any surface recognised by the glasses. This hologram can then be transformed at will and also retains these changes depending on the surroundings. This is also not changed when the user switches. When the model is displayed in the field with the correct size and position, it is necessary to ensure georeferencing over three planes that exist in both the real world and in the model. For this process, two existing right-angled building walls and the ground can be used in reality and in the model. Through a following fine adjustment, it is possible to adjust the model exactly to the existing reality.

Figure 7.7: Visualisation of the model in the Energetic Neighbourhood Quarter.

7.6 Conclusion

The analysis shows that the use of such mixed reality glasses for the planning process can be used with a lot of effort. The greatest effort is the merging process of the different specialist models. This effort has to be seen critically under inclusion of the visualisation problems but on the other hand, the visualisation of the planning is a great advantage in the whole process. The current viewers of the models through the HoloLens confirmed the high potential of the technology. They were especially impressed by the representation on the neighbourhood. The negative points of the visualisation method need to be developed further for an effective use of this technology. The most important point is the bright ambient light. For this purpose, a solution should be created that protects the user from ambient light so that the light has only a minor effect on the visual clarity of the model and no longer dazzles the user. In addition to the development of improvement possibilities the HoloLens should also be used in an entire process of urban land use planning. In this way, it can be analysed to what extent this technology can support the entire process.

In summary, this technology has potential to improve the planning process to a significant point. But this technology is still not fully developed in this context. Additional it should be possible to migrate the model quicker, when the economy sees the great potential of this evolving technology in the urban planning.

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Marvin Schnabel, Moritz Elbeshausen, Sebastian Erdmann,
Sascha Koch

8 Participatory Processes in Geodata-Based Thermal Energy Planning

Summary: The climate protection goals of the German government make it necessary to transform the building sector. To make this transformation happen the heat supply must be converted to climate-neutral technologies. The geodata-based thermal energy planning by municipalities, energy suppliers and grid operators can support the transformation. Because of the big effect on the end users, i.e. tenants and homeowners of residential buildings that are transformed in their heat supply, a paper-based survey on the topic of heat supply in Oldenburg has been conducted. Preferred areas for heat networks were identified using geodata-analysis and used as the survey areas. The letters for the survey were distributed in the four most suitable areas. The answers could be assigned to the four different areas for later interpretation of the results. In addition, more people were allowed to participate through an open online survey that was promoted in several media. In the evaluation of the survey, large differences in the number of responses between the different areas can be observed. To get a proper image of the survey areas and on the current situation of the heat sector transformation the survey has been analyzed with methods of qualitative research to gather knowledge about this research field in order to improve the process of implementing new technologies and to reach the climate protection goals. The results indicate that there is a need for information material on heat technologies and political measures by municipalities to increase potential motivation and planning security to install technologies like heat pumps and heat networks. The results of this survey can be seen as an initial approach on where to focus on in future surveys to gather additional knowledge and how to take action in order to convince as much residents and owners of buildings of a fast change of heat supply technologies.

Acknowledgement: The presented contents have been developed within the framework of the project "ENaQ – Energetisches Nachbarschaftsquartier Fliegerhorst Oldenburg", funded by the Federal Ministry of Economic Affairs and Climate Action (BMWK) and the Federal Ministry of Education and Research (BMBF) under the funding code 03SBE111.

Marvin Schnabel, Moritz Elbeshausen, Sascha Koch, Jade University, Institute for Applied Photogrammetry and Geoinformatics, Germany
Sebastian Erdmann, GloW efficiency off-grid GmbH, Germany

https://doi.org/10.1515/9783110777567-008

8.1 Introduction

The Federal Climate Change Act (KSG) of the german government demands a greenhouse gas neutrality by 2045 (sect. 3 para. 2 cl. 1 KSG). Interim targets are formulated for 2030 and 2040. By 2030 greenhouse gas emissions should be reduced by 65% relative to 1990 (sect. 3 para. 1 cl. 1 KSG). In 2040, the emissions should have been reduced by 88% (ibid.). In 2018, the building sector accounted for 13.6% of greenhouse gas emissions in Germany (Schäfer-Stradowsky 2021). This does not include emissions from the electricity demand of buildings or supply by district heating (ibid.). To achieve the targets of the KSG the building sector has to be transformed. This affects the heat supply of residential buildings to a large extent. The decarbonization of the heat supply will take place through two changes. First the efficiency of the buildings has to be increased. Second the heat supply has to be customized and must be based on renewable energies.

The transformation of the heat supply can be supported by geodata-based thermal energy planning. To perform geodata-based thermal energy planning several different information are necessary. The thermal energy demand, living area and the roof area of every building in the planning area are some examples of information that be used in the geodata-based thermal energy planning (Erdmann/Belkot/Friebe et al. 2021). Geodata-based thermal energy planning can be used to identify the best option for a sustainable heat supply structure for a planning area. The most suitable supply structure can differ between different planning areas. Possible heat supply technologies include electrical heat pumps, solar heating or heat networks.

In areas with a high building density heat networks have a high potential to decarbonize the heat supply (Hesse 2019). Further can be highter proportion of renewable energies reached in the heat supply with heat networks compared to decentral heat supply technologies (ibid.).

The change from a decentral heat supply to central heat supply through a heat network affects the end consumers. This includes that the heat supply technology and structural changes in many buildings has to be changed. The special thing about the change over to a heat network is that many building owners have to decide to change the heat supply technology of their houses at the same time and take the costs for structural changes. Another option is a statutory constraint. This would result in every owner to be forced to change their heat supply.

To evaluate the opinion of building owners and to get more information of the building a survey is conducted. The survey has been made in areas where a heat network is suitable for the heat supply. These areas have to be identified within the thermal energy planning process (Section 8.2.1). In Chapter 8.2.2 is explained how the areas for the survey were identified with a geodata-based approach including visual data discovery methods. This procedure is used for geodata-based thermal energy planning and helps defining regions of interest for the transformation of the building sector. The Chapter 8.2.3 explains the structure and the different sector of question of the survey and how the survey is performed. In the following Chapter 8.2.4 the results of the survey are interpreted. Also is described how the survey is evaluated.

8.2 Procedure of the Participation Process

8.2.1 Geodata-Based Thermal Energy Planning

The process of thermal energy planning includes the planning of the most suitable use of heat supply technologies. The process can be used to plan the heat supply from renewable energy sources (Maier 2016). There are several heat supply technologies that are based on renewable energies like solar heating or electrical heat pumps. Heat networks can be useful to transform the heat supply. The issue of thermal energy planning is currently important in Germany. It is planned to make thermal energy planning nationwide in the future (Federal Ministry for Economic Affairs and Climate Action 2022). In addition, it is planned that the building subsidies are to be linked to the thermal energy planning (ibid.). In the federal state Baden-Württemberg thermal energy planning is binding since 2020 (para. 7d KSG BW).

Due to the spatial references in thermal energy planning, geodata-based planning applications are very suitable (Mauthner/Leusbrock/Heimrath et al. 2018). For the geodata-based thermal energy planning process many information like the thermal energy consumption, the potential of using solar energy or the energetic state of every building in the planning area necessary. Additionally, information of the current heat supply structure, the age of the technical supply facilities, regional potentials for the use of renewable energies or industrial waste heat are necessary for the planning of heat networks (Reckzügel 2019).

In the thermal energy planning process two viewing levels are important (Erdmann/Belkot/Friebe et al. 2021). The first viewing level is the buildings level (ibid.). In this viewing level the individual buildings are considered. At the building level can be determined whether a building can be supplied with decentral heat supply technologies (ibid.). The second viewing level is a higher viewing level in which not every single building is considered. In this viewing level buildings are aggregated. To evaluate the heat network suitability the second higher viewing level is necessary. On the higher viewing level buildings can be considered together. For example the planning area can be subdivided in a grid. This gives the option to consider the buildings in a grid cell together. To ensure an economically efficient operation of a heat network and to reduce heat loss the heat line density has to be high (Wetter/Brügging/Willenbrink et al. 2018). The heat line density describes the thermal energy sale per year and per meter route length (ibid.).

There are several steps in the geodata-based thermal energy planning. The process of the geodata-based thermal energy planning is shown schematically in Figure 8.1. In the first step an inventory analysis is made. In this inventory analysis information of energy consumption is collected. Also information of the infrastructure like the gas grid and power grid are collected. The second step is a potential analysis to evaluate the potential of using renewable energies or industrial waste heat. Furthermore, the potential for increasing the energetic condition of buildings is evaluated. In the third step scenarios are developed. After developing the scenarios a transformation strategy is created. The transformation strategy describes the steps that have to be made to achieve the targets.

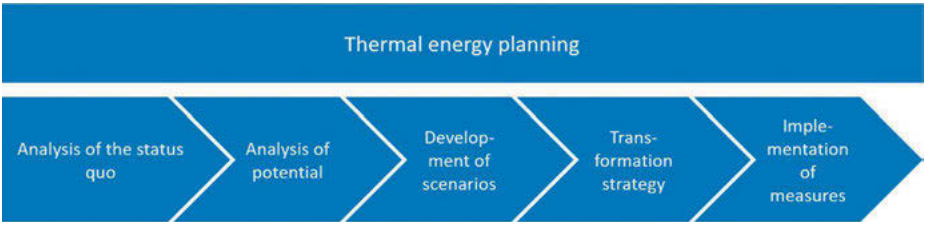

Figure 8.1: Schematic representation of the thermal energy planning process (based on (Ministerium für Energiewende, Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein 2014)).

8.2.2 Identification of the Survey Areas

The main goal is to make a survey in areas where the use of a heat network for the heat supply in the areas would be suitable. The identification of the areas is done with an application that was developed to support the geodata-based thermal energy planning. The application uses the concept of visual data discovery to give the users the opportunity to analyze the data in an intuitive way (Schnabel/Gravenhorst/Belkot et al. 2022).

The database includes information like the thermal energy need, the use or the living space of every building in the planning area. This information can be used directly. Other information have to be calculated in performed GIS analyses. The identification of decentral buildings for example can be done using GIS analyses. Another GIS-based analyses that has to be performed is the anticipation of the route for heat networks. The route is necessary to calculate the heat line density as mentioned in Chapter 8.2.1. The software Tableau is a visual data discovery software and is used to visualize the information. Tableau gives the possibility to create dashboard and data stories that describe the specific dataset to visualize various information like the energy consumption date of building or the heat line density. To visualize the information various visualization options such as maps, histograms or tables are available. Dashboards can be made for every topic to show an overview of the information (Federer/Joubert 2018) to make a comparison between the information possible (Tableau Software LLC. 2021). To support the geodata-based thermal energy planning several dashboards and data stories were created. As mentioned in Chapter 8.2.1 there are two important viewing levels for the thermal energy planning. The view on every single building in the planning area and a superordinate level. To implement the two viewing levels the dashboards “Building Level” (German: Gebäudeebene) and “Grid Level” (German: Rasterebene) are created. The dashboard „Grid Level“ can be seen as main dashboard and is shown in Figure 8.2. To create the higher viewing level a grid with an edge length of 500 m is used. The grid can be seen in Figure 8.2.

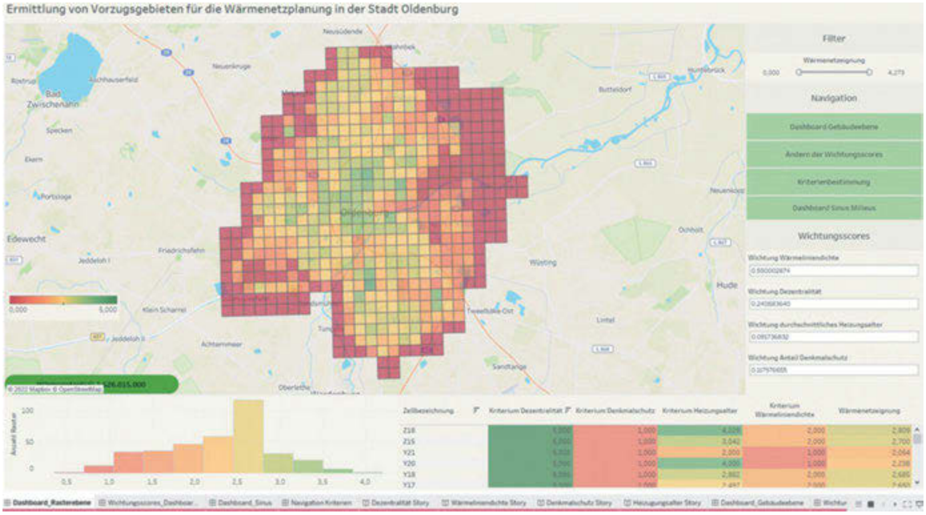

Figure 8.2: Dashboard Grid Level (background map: © Mapbox, © OpenStreetMap, © GeoBasis-DE / BKG (2022)).

It is presented on the ”Grid Level” dashboard and is placed onto a map of the planning area. The grid is used to visualize the heat network suitability. The color of the grid cell depends on the heat network suitability that is calculated for the grid cell. Red cells are not suitable for heat networks and green cells have a high heat network suitability. The heat network suitability is calculated by a multi-criteria decision analysis. The criteria for the multi-criteria decision analysis are the proportion of decentral buildings and buildings with monument protection in the grid cell. Furthermore the average age of the heat supply technology and the calculated heat line density have been used to improve the meaningfulness of the suitability score. The weighting factors of the criteria are calculated through an analytic hierarchy process. The analytic hierarchy process includes a pairwise comparison. With this pairwise comparison the user can change the weighting factors. The heat network suitability can assume values between zero and five. On the raster layer dashboard there is a possibility to filter by the heat network suitability. With a slider the range in which the grid cells are visualized can be manipulated.

To produce results that can be analyzed properly a bottom-up sampling, including every data row from the survey, has been performed to get survey groups from the

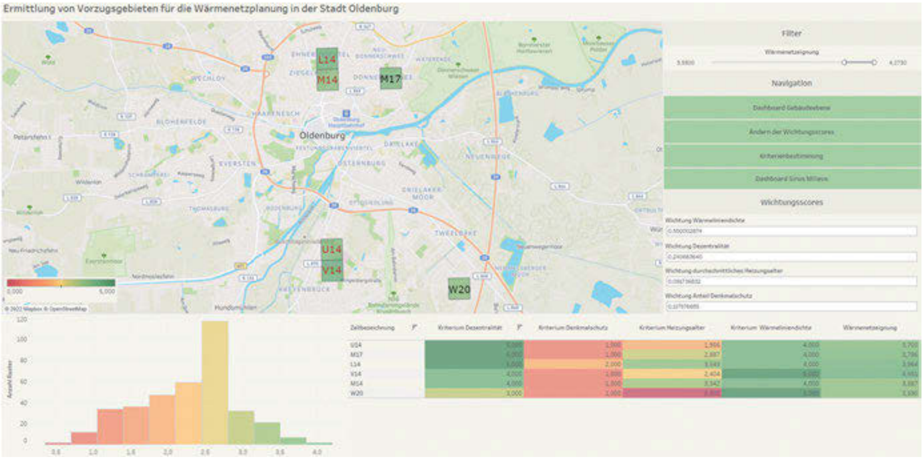

Figure 8.3: Identification of grid cells with a heat network suitability higher than 3,58 (background map: © Mapbox, © OpenStreetMap, © GeoBasis-DE / BKG (2022)).

raw survey data that fit the requirements of qualitative research (Steffen/Doppler 2019). To achieve this, a parameter had to be identified that can be used to analyze the area based on its consistency in the survey area. This so called maximum similarity principle has been applied using the heat network suitability (ibid.). The filter feature is used to search for grid cells with a high heat network suitability. In Figure 8.3 areas identified with a heat network suitability of 3,58 or higher are displayed. There are six grid cells with a heat network suitability of 3,58 or higher. It can be seen that there are two grid cells that stand alone and there are two pairs of grid cells. These pairs of grid cells are interesting for a survey about heat supply. The similarity and comparability of the survey regions based on the predicted heat capacity can be used to deduce possible findings from the survey as part of the evaluation (Steffen/Doppler 2019).

8.2.3 Survey on the Topic of the Heat Supply

In Chapter 8.2.2 six grid cells were identified with a heat network suitability of 3,58 or higher. As mentioned, there are two pairs of grid cells and two single grid cells. For the survey the two pairs are selected. This decision is made because of the big effort that is caused by the survey and with the four grid cells can two bigger areas that are suitable for a heat network part of the survey. The grid cells of the northern pair have the names L14 and M14 and the grid cells of the southern pair are called U14 and V14. In the selected grid cells letters were distributed to every residential unit. The letter contained a QR-Code that leads to the survey website. It is important to notice that the answers can be assigned to the areas to identify the amount of answers per area. This makes it possible to evaluate the results for every single area separately. To get more data, an open survey helped with acquiring additional answers from other areas. The open survey was advertised on several websites and in the local radio.

The survey consists of questions from three different sectors. Most of the questions are multiple choice but there are also questions that can be answered with free text. The first sector includes questions on the subject of buildings. The second sector focused on the heat supply and the energetic status of the building. This sector includes questions on the heat supply technology for the residential heating and the hot water needs. Further questions on the topic of the energetic status of different components included. In the end of this sector are questions on the topic of heat networks. The third sector focused on the electrical energy and includes questions about the electric energy consumption and production of the building. This includes questions on the kind of the electricity tariff that is used but also on technologies to produce electricity with renewable energies like solar power systems for the balcony or small wind turbines. This section is important to get information on the electrical sector. This is important because of the sector coupling that connects the electrical sector and thermal energy sector through technology like electrical heat pumps.

To evaluate the survey a couple of assumptions have to be made. Due to the highly complex topic of energy and heat supply there was a low amount of responses from survey participants per area. That does not impact a qualitative approach though (Steffen/Doppler 2020). Also a lack of interest in answering questions about buildings that are not owned by survey participants could also have affected the outcome. Due to the fact that home owners tend to have a bigger interest in giving information and participate in surveys about their property this was expected. But even though this result is expected it should be mentioned, that inhabitants of buildings should be informed about future changes and given the chance to develop interest in these topics as they profit directly from changes in the heat infrastructure.

This study result should not be evaluated based on classic quantitative methods but with qualitative research. This is due to the highly exploratory field of study that has been part of this survey. Also the topic is not much researched and there was only little information about possible parameters to formulate questions that can be analyzed statistically (Steffen/Doppler 2020). This is why the survey is evaluated based on an exploratory approach which is typical for open research questions and can be used to identify problems or increase knowledge about the topic itself and possible theories (ibid.). Exploratory research can be used to get a better understanding of the topic and relations between variables that impact this field of energy transformation (Magerhans 2016). The goal is to identify the topics which are of great interest to the public and have strong need for action by the government to reach the climate protection goals. This effort is realized within exploratory studies like this that increase the knowledge base to define new hypothesis and research questions in the future (Magerhans 2016).

To interpret the results, an in depth understanding of the present situation of the heat and energy market, knowledge about different technologies and the current situation of survey participants is required. This is why the survey consists of questions that ask about these specific topics in addition to the energy topics. In this field of modern technologies for the German energy transition and climate protection efforts it is mandatory to evaluate the results of this survey based on parameters like behavior, motives, attitude and expectations of participants (Steffen/Doppler 2020). Due to the difficulty of defining possible parameters for a quantitative study result, it is necessary to further elaborate what parts of the survey resulted in what answering behavior for example in the form of given or missing answers (ibid.). Some questions may have caused difficulties for participants as well as the question about the amount of questions that participants were able or willing to answer.

8.2.4 Interpretation of the Survey Results

The results of this study can be categorized by the three different answer groups of the survey. These groups have been predefined by the survey creators and were mentioned in Chapter 8.2.3. The groups were used to evaluate the given answers in the context of the related topic. This helps identifying information that can be used to interpret the survey answers. Based on the survey results, interpretations for significant answer results have been made with assumptions about the stated parameters like for example the motives of participants or their socio-economic situation. Keeping in mind the behavior, motives, attitude and expectations of the participants, there were several results for each part of the survey. Overall the received answers were quite behind the expected amount.

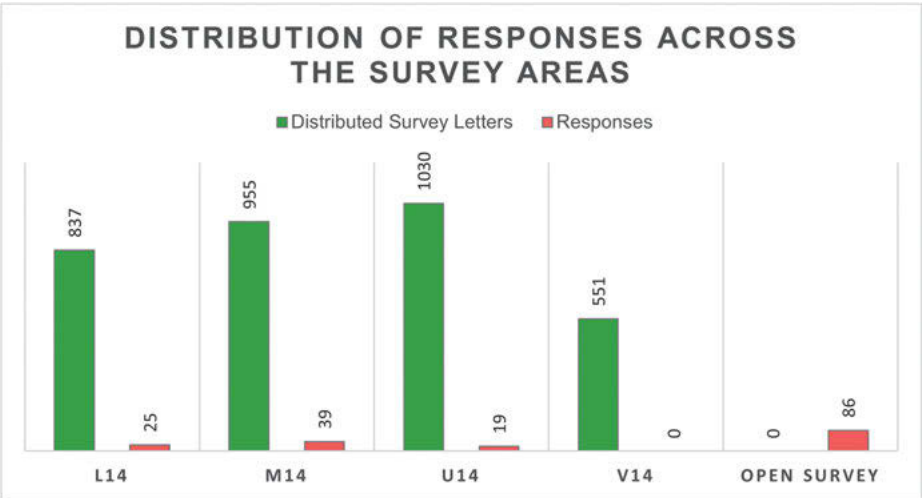

Figure 8.4: Diagram of the response distribution from the survey in each study area and the open survey.

From the 3373 letters that were distributed to known addresses in the study regions only a small amount of 83 of the inhabitants have responded to the survey. This is a percentage of 2,46%. The amount of answers ranges between 0 and 39 in the different grid cells. The grid cell (V14) is standing out because there were zero answers as displayed in Figure 8.4. The open survey on the other hand resulted in 86 participants who answered the survey questions.

As it is hard to acquire solid information on possibly interested groups for these kind of surveys and the number of participants is below the expectations, it is most likely, that the results are not representative (Steffen/Doppler 2020). But this does not mean it is unlikely to produce results that can be used further. This survey showed several interesting results if the outcome is examined further. For each of the questions in the topics building state, radiators and energetic status and use and production of electricity an assumption based evaluation that implies motive, behavior, attitude and expectation has been made. These assumption results are based on the percentages of given answers as well as comments that could be added by participants.

The results show, that questions about building state seem to be answered very homogeneous over each of the study areas excluding the grid cell V14. In every survey area and in the open survey many participants say that a renovation of the windows is the most important action to take. Differences can be seen between participants of the survey regions and the participants of the open survey. In the survey regions more participants answer that they are tenants rather than owners. In the open survey a few more participants say that they are owners than tenants. It is noticeable that heat technology based on natural gas is the most common one. In the open survey there was a significant increase in newly installed radiators. Based on possible motives of participants in open surveys it is highly possible, that the personal threshold to participate in surveys of more complex energy topics is lower if participants were confronted with it in the near past or have made the decision to take action themselves. Noticeable is that many inhabitants who answered in the open survey that they have a relative new heat supply answered that they have a heat supply based on natural gas. It can be mentioned that the most participants of the open survey said that carbon dioxide emissions and ecology are very important or important to them. This does not correspond with the facts that many participants have a heat supply based on natural gas and that there are more owner than tenants under the participants of the open survey.

On the other hand, a significant amount of the participants in each of the survey areas are worried about raising energy prices due to the carbon dioxide tax. This is not the case for the open survey which corresponds with the fact, that the overall interest in ecology is higher in this group. The difference in ecological motives can be seen when asking for possible future connection to a local heat network. Most of the participants have answered, that if the heat networks have an ecological benefit the would not mind or possibly file a lawsuit if the heat supply is transitioned into heat networks and most of the participants in all study areas except one agree with the transition to alternative technologies like heat networks. As an argument against heat networks the participants stated missing technological capacities of heat distribution networks in a real climate neutral heat supply scenario. In all survey areas, it is noticeable that the participants say that they need more information about heat networks. Interesting is that in the open survey just a few people say that they need more information about heat networks. This shows that the participants of the open survey and the survey in the different areas have a different knowledge about heat supply technologies. In the survey where questions on the topic compulsory connection for heat networks. Most of the participants accept a compulsory connection when the use of a heat network is reasonable in an ecological perspective. Some participants say that they would file lawsuits against a compulsory connection to a heat network. After the question about a compulsory connection to a heat network there was an explanatory text about compulsory connection and the conditions of it. The conditions included a carbon dioxide free heat production for the heat network. That means that the carbon dioxide Tax would not effect the price of the thermal energy that is distributed through the heat network. Further it was explained to the participant, that the price of the thermal energy would not be higher than the heat supply with natural gas. After this information text, the question was asked a second time. It can be seen that the participants who said that they would be willing to file a lawsuit against a compulsory connection would not change their mind even if given this additional information.

The sector of question on the electrical supply includes a question about electricity tariff. Differences between the answers of the different survey areas can be seen. In the grid cells L14 and M14 more than the half of the participants say that they have a green electricity tariff. In the grid cell U14 the percentage of the participants with a green electricity tariff is much lower. In the open survey the percentage value is nearly the same as in the grid cells L14 and M14. In this sector of the survey were questions about several technologies to produce green energy like solar power system, small solar power systems with a maximal power of 600 W that can be installed at balconies or small wind turbines that can be installed on buildings. In the survey areas just a few participants say that they were willing to install a small solar power system. In the open survey more of the participants would be willing do that. Another question that focused on small solar power systems asked whether the participants already have searched for information of small solar power systems. In the open survey more participants replied that they have informed themselves compared to the survey areas. In contrast to that the participants from the survey areas mostly say that they have not informed themselves about technologies. It is therefore noticeable that more participants in the survey areas would install a small wind turbine than in the open survey.

As a result of the survey interpretation it can be said that the answers indicate, that inhabitants need more information about possible heat and energy topics as well as climate neutral technologies and heat networks. For example some real numbers like a cost benefit for heat energy prices or a reduced carbon dioxide footprint resulting from the use of new climate neutral technologies could help increasing information for survey participants. This additional information could be presented to survey participants in the beginning to increase the willingness to answer the survey questions. The complex decision making in this field that does not really include inhabitants living for rent makes this problem difficult to solve. But owners can also lack the information to decide whether they can install a heat pump or if a local heat network is available to connect to. This leads to some cases where fossil technologies were installed in the past years even though new technologies were already available. In these cases where non-fossil technologies like heat pumps and heat networks could have been the more resource-saving option when it comes to climate questions or with economic foresight in the future energy market. The missing information or financial incentive to invest in modern technologies can be addressed by using supportive measures from municipalities. The survey showed that it is advisable to support owners and tenants equally with information material about window and heat system renovation strategies. Also the question about missing interest in the heating system for tenants raised the concern, that missing knowledge about their rights may prevent tenants from participating in decisions regarding renovation measures. Alternative technologies could improve the interest of inhabitants for energy and heat topics. This includes increasing individual solutions like balcony solar panels and small wind turbines. It can be seen that there is more information on the possibilities and advantages of solar power systems is needed. Also can be seen that many participants of a high interest in small wind turbines. It can be useful to think of support program of municipalities for small wind turbines. The survey showed that it is helpful to identify specific regions of interest for thermal energy planning to address the people living there early and inform them about possibilities for their houses. It also showed that municipalities need to improve their information material to reach owners of buildings that may be interested in renovating their buildings and install a heat pump of connect the building to a heat network.

8.3 Conclusion

Exploring this survey creates the opportunity to generate new information in this research topic. This may help defining better survey questions in the future to further evaluate the topic of energy and heat transition, gather information of the public opinion on the current state of buildings as well as future technologies and acceptance. This information can then be used to create studies to quantitatively evaluate the topic of heat and energy supply and get a better understanding of possible projects to accelerate the climate change efforts implemented by the government and reach the climate change goals until 2035. If this process is not improved the goals of the government, to reach climate neutrality until 2045 and to speed up the transformation process could possibly be failed due to the lack of actions that have to be taken now. Oldenburg as a municipality that has set its climate protection goals even more ambitious could suffer the consequences of this missed out opportunity. The survey results indicate, that there is a lot of ambiguity about how this process will be implemented and this causes residents and owners to be uncertain what actions to take. This ultimately leads owners to the common solutions of fossil technologies and stands in contrast to the task of reaching climate neutrality in Germany which is a difficult task anyway. Following surveys to accumulate an in depth knowledge about the topics of heat supply technologies and acceptance in the public have to follow and quantitatively evaluate this results. To tackle the problem of missing information or motivation for home owners or residents municipalities have to implement an improved process of information and support that provides relevant information material for both owners and tenants and reaches as many owners and tenants as possible and helps to convince them to use alternative energy sources and modern heat technologies like heat pumps, heat networks and solar thermal solutions in their buildings.

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Katja Walther

9 Climate District Neue Weststadt

Summary: The lighthouse project „Klimaquartier neue Weststadt Esslingen" is, to the best of our knowledge, the first development project in Germany to integrate the production of green hydrogen into an urban district. The centerpiece of the innovative energy concept at the heart of the project consists of two electrolyseurs and a hydrogen tank which, for urban-planning reasons, are housed in an underground energy center. Based on reducing electricity, heat and cooling demand at best possible costs on the one and applying innovative technologies on the other hand, the aim is to put the deployment and the capabilities of a grid-friendly operation of an electrolyseur in an urban envirnment to the test. Feeding the emerging waste heat into a district heating network strongly increases the over all efficiency, while the green hydrogen is available for further use in branches as industry and mobility. Road-testing this innovative approach on a technological as well as a legal level, the „Klimaquartier Neue Weststadt" proves to be an ideal living lab.

9.1 Introduction

9.1.1 The „Neue Weststadt" and its History

In the year of 1874, the gas plant of the city of Esslingen am Neckar was relocated from the station square to the western end of the then fragmentarily emerging new industrial area in the west of Esslingen's old town, which is shown on top in Figure 9.1. No one could have predicted that this was the initial spark of a development that would one day culminate in a research project demonstrating, for the first time in Germany, that the production of green hydrogen in urban context is not only possible but economically feasible. Yet, the reestablishment of the gas plant in Esslingen's West almost 150 years ago triggered a consistent development of the city's first industrial area. Tool and machine-tool factories as Fritz Müller, Dick and Boley moved to the West and became corner stones of the industrial landscape of Esslingen, as did the companies Hengstenberg and Quist. By the year 1899, the landmark buildings that are still characteristic of the cityscape in Esslingen's West, as can be seen below in Figure 9.1, were established.

From the beginning, factory buildings stood side by side with their owners' villas. When the first complex for workers' housing was added by 1897, the mixed use of the area, which has been a characteristic feature of Esslingen's West ever since, was established. Even when the new industrial area's luster began to fade and further development measures became necessary, this mix distinguished by the combination of

Katja Walther, City of Esslingen Neckar Sustainability and Climate change, Germany

https://doi.org/10.1515/9783110777567-009

Figure 9.1: The area of today's Weststadt in 1885 (top) and 2017 (bottom).
(Source: municipal archive Esslingen (top), DESIGN4EYES (bottom))

living and working survived the continuous change Esslingen's West was exposed to otherwise.

The reorganisation and reconstruction that took place during the second half of the 20th century, though, did not necessarily reflect that specific character anymore. The new buildings met the spirit of the age but not the district, a trend that earned it the nickname „Esslingen's Wild West", and brought on the decision to establish a re-development. In this context, the label „Weststadt" was coined.

The grounds of the former freight yard were already derelict during the studies for the redevelopment and were always considered as a potential development area. After the site had been purchased from the German Railways (Bahn AG) in 2010, the first steps for further urban development were promptly initiated. In 2011, the urban design competition „Neue Weststadt Esslingen“, including the area of the former freight yard, was held.

On the basis of the winning design by LEHEN drei Architektur Stadtplanung, Stuttgart, as presented in Figure 9.2, the consecutive steps of establishing a development framework, and implementing a successful public participation as well as an investor selection were completed by 2012. When it had also been decided that the new building of the University for Applied Sciences in Esslingen would be integrated in the concept, the competitions for the individual realisation for the building blocks A to E began in the year 2014.

Figure 9.2: The „Climate district Neue Weststadt“.
(Source: LEHEN3, siz energieplus)

One of the most decisive steps on the way to the present lighthouse project „Klimaquartier Neue Weststadt was the municipal council’s resolution of the urban development contract in order to guarantee architectural design and construction quality for the Neue Weststadt. Aside from the determination of individual competition proceedings for each building block and public space, standards for façade and open space design and the fixing of the historically purported mixed use, the contract also demands the climate-neutral operation of the buildings themselves. To meet this demand, innovative energy concepts and the extensive establishment of photovoltaics became an integral dimension of the „Neue Weststadt“.

Thus, the stage for the lighthouse project „Klimaquartier Neue Weststadt“ was set.

9.1.2 Where we are Coming from

In November 2017, the application the City of Esslingen am Neckar had submitted as main applicant for the 6th Energy Research Programme was granted. The lighthouse project „EnStadt. ES_West_P2G2P“, which later was named „Climate District Neue Weststadt“, started out with a strong, interdisciplinary consortium consisting of seven project and three affiliated partners from the areas of research (technical and sociological), application and civic participation and has even grown ever since.

The Partners

The scientific and organisational overall coordination is provided by the Steinbeis-Innovationszentrum energieplus (Stuttgart). As a project developer for mainly residential real estate, RVI (Saarabrücken) functions as investor and housing company. The Berliner Institut für Sozialforschung BIS (Berlin) sociologically monitors the project with a clear emphasis on the local residents. As a specialist for sustainable and climate compatible construction, the Institute for Building Climatology and Energy of Architecture with the Technische Universität Braunschweig (Braunschweig) focuses on the simulation tools applied. The Institute for Sustainable Energy Technology and Mobility – INEM with the University for Applied Sciences Esslingen (Esslingen) works on mobility concepts (private and public transport) and the subsequent technical monitoring. The key point of a zero-emission public transport is covered by the local municipal transport services SVE (Esslingen). The energy supplier Polarstern (München), specialised in eco-energy, is responsible for operating the central energy systems as well as the concepts for tenant’s electricity supply. The development of a user interface for the private and public sphere is implemented by the softwaren d application developer Monday Vision (Stuttgart). The Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg – ZSW (Stuttgart) contribute their core competence of generation and conversion of chemical energy sources. HyEnTec Ltd is concerned with the scope of hydrogen mobility within the project, whereas Green Hydrogen Esslingen Ltd. (Esslingen) operates the electrolysis system as well as the associated technical equipment. Together with the City of Esslingen am Neckar, Blumberg Ltd. (Esslingen) works on the design of the project-based public relations as well as the newly established information center, which is shown in Figure 9.3.

The Objectives

With its climate and energy agenda, the German federal government aims at sustainably creating nearly climate neutral buildings. The lighthouse project „Climate district Neue Weststadt“ will implement and test one approach towards this goal. The quarter’s

Figure 9.3: The information center on the day of its official opening.
(Source: Maximilian Kamps.Agentur Blumberg GmbH)

energy-concept is based on a cost-optimised reduction of electrical, heat and cooling demand of the buildings while supplying mostly from renewable sources. Innovative technologies as electrolysis in an urban context are integrated in a system-optimised manner.

Germany's long-range objective of supplying electricity mainly from renewable sources will cause both overproduction and shortages, especially regarding the seasonal mismatch-situation concerning generation and demand. Converting electricity surpluses to gas (power-to-gas, P2G) enables its delayed use and can thus be a future technology of great potential – especially regarding security of supply. The „Climate district Neue Weststadt" is to be developed as a test rig, researching the usability and the potential of an electrolyser in the context of urban quarters. The electrolyser's energy intake is to be supplied from local sources (photovoltaics, shown in Figure 9.4) and fluctuating regional renewables. There is a special focus on integrating the unit to optimise network operation. Another key point is the usage of heat released during the electrolytic process as source for a local heat network to maximising overall efficiency.

By closely monitoring the project technically as well as social scientifically, the interaction between building, technology and residents is assessed to prove the functionality and suitability for everyday use – also with respect to future application in the national grid that guarantees a reliable energy supply from renewable sources. The monitoring will furthermore contribute to the optimisation of the building operations and provide insight into the transferability and acceptance of corresponding future projects.

The „Klimaquartier Neue Weststadt" (Figure 9.5) is therefore a prime example of a living lab: under real-live conditions and according to the existing legal basis, development, implementation, and operation of concepts, technologies and products is

Figure 9.4: Solar panels on the roof of building blocks B ("Bèla", front) and C ("Citadis", back). (Source: Maximilian Kamps, Agentur Blumberg GmbH)

tested, while providing spaces for participation. On the one hand, the temporally as well as spacially restricted work on the living-lab „Klimaquartier Neue Weststadt" aims at demonstrating innovative technological and economical options for municipalities to contribute to the necessary energy turnaround. On the other, it offers findings regarding potentially needed developments of present legal framework, e.g. the authorisation of putting up electrolysis systems in urban environment. Public involvement in order to promote acceptance of new technologies as well as their application is also put into practice: public outreach via information events, the project webpage and not least the local information center is accompanied and evaluated by social monitoring. The high quality of the living lab „Klimaquartier Neue Weststadt" was confirmed in May 2022, when the lighthouse project was rewarded the Special Award „Sustainability" within the Innovation Award Living Labs by the Federal Ministry for Economic Affairs and Climate Action.

9.1.3 Where we Stand

The centerpiece of the „Climate district" is the energy supply concept. It follows a sustainable approach and focuses on connecting the electricity-, heating-, cooling- and mobility sectors on a local level. The technical infrastructure including a so-called „energy center" was integrated in the building structure of one of the quarter's building blocks. There, surplus renewable power from the local photovoltaic systems as well as from supraregional generation will be converted into "green hydrogen" by electrol-

Figure 9.5: “Klimaquartier Neue Weststadt” in May 2020 with the finalized building blocks B (far right) and C (right) and block D (“Desiro”, left) under construction against the backdrop of Esslingen’s wineyards, Weststadt and historic district.
(Source: Maximilian Kamps, Agentur Blumberg GmbH)

ysis. The hydrogen can be stored short-term and/or fed into the local gas grid during the first stages of green hydrogen production. At a later stage of the project, most of the hydrogen will be transferred to a filling station and from there distributed to customers in the industrial or public transport sector by trucks. It is aspired to supply the hydrogen demand of local industries in Esslingen am Neckar in order to keep transport emissions at a minimum. Initial inquiries and negotiations have been conducted with promising outcome.

The energy center was officially opened in June 2021 and contains the elctrolysis systems, a H_2-tank, batteries as well as the necessary security equipment. Due to urban development requirements, it was realised as an underground structure in the center of the „Neue Weststadt" and is now located south of the future „Block E“ (Figure 9.2). Due to the unique character of the center, which for the first time included the production of green hydrogen in an urban context, the authorisation process was intense, on the technical as well as the temporal level. The approval procedures went hand in hand with the founding of the operating company. When the „Green Hydrogen Esslingen Ltd“ was established in 2019, the basic prerequisites for a successful project implementation were created.

Ever since, the realisation of the „Climate District Neue Weststadt“ has been gathering momentum. In November 2020, the hydrogen tank as shown in Figure 9.6 was introduced to the energy center; the first electrolyser, which is depicted in Figure 9.7, followed suit in January 2021. The opening celebrations in June 2021, a part of which can be seen in Figure 9.8, were overshadowed by the necessary hygiene regulations

Figure 9.6: The hydrogen tank is lowered into the underground energy center.
(Source: Maximilian Kamps, Agentur Blumberg GmbH)

Figure 9.7: One of the electrolyser systems.
(Source: Maximilian Kamps, Agentur Blumberg GmbH)

due to the SARS-CoV-2-pandemic. Yet, thanks to a carefully thought through and equally diligently carried out concept, the event was a success and digitally accessible for a wider public. In the further course, the INEM, responsible for mobility concepts in the private and public sector, founded the „Mobilitätsverein" – an association open for anybody to support and promote a local car sharing system within the quarter. A first survey among residents was carried out and analysed by the BIS; a second is well on the way. The user interface that will allow residents to obtain prompt and purposive information regarding their energy behaviour or available tariffs will be completed by mondayvision shortly. Even though the pandemic situation so far did not allow for an opening yet, the information center, offering an interactive project-related exhibition and a small meeting room, has been established in September 2021 by the Agentur Blumberg and the City of Esslingen and will open its doors for the public soon, pandemic conditions permitting.

Figure 9.8: The opening celebrations in June 2021.
(Source: Maximilian Kamps, Agentur Blumberg GmbH)

Of course, there also remain some open aspects. The construction of the new building for the University for Applied Science Esslingen already is well under way, whereas Block E so far remains in an advanced planning state. A car sharing system, including hydrogen vehicles, still needs to be established and the information of the general public as well as the residents, which had to be scaled back in the face of the pandemic, needs to be intensified during the remaining project duration.

9.1.4 Where we are Going

One of the objectives of the „Climate district Neue Weststadt" is to show the transferability of the local production of green hydrogen in an urban context. Taking a page of its own book, the City of Esslingen aims at perpetuating the principles developed during the current lighthouse project: in another transformation process on an area adjoining the „Climate district Neue Weststadt", the project „WestEnd", shown in Figure 9.9, will be developed between the new university building in the South and the Rossneckar

Figure 9.9: The area of the WestEnd (foreground) and the Pliensauvorstadt (right of the river).
(Source: Maximilian Kamps, Agentur Blumberg GmbH)

Canal in the North. As a possible contribution of the City of Esslingen to the International Building Exhibition IBA '27, the so far commercially used area will be transformed into a site of new forms of future-oriented, climate-neutral living – including the production of green hydrogen.

While the ambitious plans for the WestEnd are promoted, efforts have begun to realise the above mentioned filling station which originally was intended to be constructed on-site the WestEnd area. Due to urban development requirements, though, it is now planned to establish this industrial structure on the opposite bank of the river Neckar in the district Pliensauvorstadt. The recent restructuring process of the industrial area located there offers an excellent opportunity to integrate a filling station from where the locally produced green hydrogen will be transported on to customers in the industrial or public transport sector. A feasibility study on an underground hydrogen pipeline, which would have to tunnel under the railway, the river Neckar as well as the main road B10, looks very promising. First exploratory talks with resident business and industries also encourage optimism that this solution will be achievable.

Network Partners Climate District Neue Weststadt

The Climate District Neue Weststadt is one of the six lighthouse projects in Germany funded by the Solar Building/Energy Efficient City funding initiative. Under the scientific and overall coordination of the Steinbeis-Innovationszentrum energieplus, the following twelve further partners from the municipal, research and industry sector as shown in table 9.1 cooperate within the scope of the Climate District Neue Weststadt.

Table 9.1: Partners of the project "Climate District Neue Weststadt".

1	Stadt Esslingen am Neckar	Rathausplatz 2	73728 Esslingen a.N.
2	Steinbeis-Innovationszentrum energieplus	Gropiusplatz 10	70563 Stuttgart
3	Institut für nachhaltige Energietechnik und Mobilität (INEM), Hochschule Esslingen	Kanalstraße 33	73728 Esslingen a.N.
4	Institut IGS, Technische Universität Braunschweig	Mühlenpfordtstraße 23	38106 Braunschweig
5	RVI GmbH	Beethovenstraße 33,	66111 Saarbrücken
6	Städtische Verkehrsbetriebe Esslingen	Heilbronner Str. 70	73728 Esslingen a.N.
7	mondayvision	Gropiusplatz 10	70563 Stuttgart
8	Polarstern GmbH	Lindwurmstraße 88	80337 München
9	Green Hydrogen Esslingen GmbH	Abt-Fulrad-Straße 3–5	73728 Esslingen a.N.
10	Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)	Meitnerstraße 1	70563 Stuttgart
11	Berliner Isntitut für Sozialforschung (BIS)	Brandenburgische Str. 16	10707 Berlin
12	Hyentec GmbH	Gaußstrasse 42 A	70193 Stuttgart
13	Agentur Blumberg GmbH	Georg-Christian-Kessler-Platz 6	73728 Esslingen a.N.

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Norbert Fisch, Tobias Nusser, Simon Marx

10 Climate Impact of Green Hydrogen in an Urban Context

Summary: Green hydrogen is a key element in achieving the climate policy goal of greenhouse gas neutrality and decarbonisation of all consumption sectors. The article shows how the P2G&H concept approach works and what contribution it can make to climate protection. With the P2G&H concept, green hydrogen is produced nearby the consumer in an urban context and the resulting waste heat is used.

The article first explains in detail the basic boundary conditions for the highest possible climate protection effect of the P2G&H concept. The basic requirements such as the use of renewable electricity, the utilisation of emission-free waste heat and the climate protection effect through the substitution of fossil energy sources are classified and described.

In the second part, the concrete implementation of the P2G&H approach in the district "Neue Weststadt" in Esslingen is discussed. In addition to the description of the energy supply concept, this article explains the concrete experiences in the planning and implementation of a MW electrolysis plant from the planner's and operator's point of view. These topics are supplemented by insights and findings from the approval process.

10.1 Climate Protection Requires Green Hydrogen

There is political consensus on the importance and need for decisive and systematic climate action. In addition to complying with the international climate protection agreement in Paris, the German government has set itself the goal of being climate-neutral by 2045. This effectively means that the decision to phase out the use of fossil fuels has been taken.

The resulting political and societal challenge of the energy transition means a fundamental transformation of our industry, energy and transport sector. Because climate neutrality or greenhouse gas neutrality require a consistent reduction in greenhouse gas emissions towards "zero". In order to make it possible to phase out the use of fossil fuels, renewable energy sources such as photovoltaics (PV) and wind power are to be expanded significantly. The expansion potential of PV and wind power in Germany is still large enough to be able to provide a significant share of future energy supply. The German

Norbert Fisch, SIZ energieplus, Germany
Tobias Nusser, SIZ energieplus, Germany
Simon Marx, SIZ energieplus, Germany

https://doi.org/10.1515/9783110777567-010

government is planning to increase the installed PV capacity from around 55 GW today to 200 GW by 2030, which corresponds to an average increase of 18 GW/a (BMWK (2022)).

The aimed decarbonization of the energy, building, industry and transport sectors is leading to increasing electrification. In many applications in industry and in heavy goods traffic, however, direct use of the fluctuating renewable electricity is neither useful nor possible. PtX measures are therefore a prerequisite for a cross-sectoral and cost-optimized energy transition. Secondary energy carriers, such as green hydrogen from electrolysis, must be able to make a significant contribution to substituting gray hydrogen in industry or fossil fuels in heavy goods traffic in the future.

10.2 Concept P2G&H – Green H_2 with use of Waste Heat

Scientific studies confirm the central role of hydrogen on the way to a climate-neutral energy supply system. The analysis of the research center Jülich on the "Transformation strategies for the German energy system up to the year 2050" (FZJ (2020)) puts the future hydrogen demand in Germany at up to 12 Mt per year.

Assuming that around half of this hydrogen is produced in Germany, required generation capacities in the form of electrolysis plants result with an electrical output of around 50–60 GW. The prerequisite for this is an energy-friendly mode of operation for the electrolysers, in which electricity is drawn from the grid, especially at times when there is a high proportion of renewable energies. The average number of annual full-use hours with this operating approach is in the range of 4,000–5,000. The waste heat resulting from the process amounts to around 110 TWh per year. According to AGEB (2021), this amount corresponds to the final energy consumption of district heating in Germany (105 TWh in 2020).

The strategic and economic policy task now consists of making the ramp-up of the hydrogen industry particularly efficient and raising this waste heat potential as far as possible. The P2G&H concept follows this claim. Decentralized electrolysers in the urban context generate green hydrogen in close proximity to the consumers. For high efficiency, the waste heat is used to supply buildings or to feed into heating networks. With this approach, the efficiency of hydrogen production can be increased from 55–60% up to 80–90%. In addition, long transport routes can be avoided with the consumer-oriented production and a high regional added value can be achieved.

The conceptual approach to the production and utilization of green hydrogen is shown in Figure 10.1.

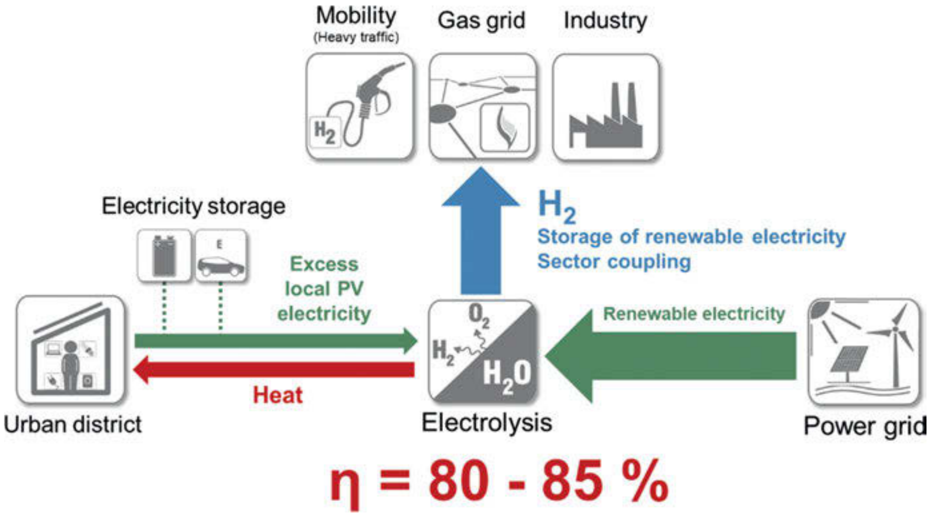

Figure 10.1: Scheme P2G&H.

10.3 Impact on Climate Protection and Energy Transition

Green hydrogen is required to achieve climate protection goals. The concept of decentralized production of green hydrogen in urban districts with combined use of waste heat (P2G&H) convinces with high efficiency and the added value of local energy cycles. The approach has a particular climate protection effect if the green hydrogen from renewable electricity is used to directly substitute fossil fuels in the industry and transport sectors.

In the following chapters, the essential basic requirements for a maximized contribution to climate protection and the achievement of the energy transition goals are explained.

10.3.1 Use of Renewable Electricity

Hydrogen as a substitute for fossil fuels only unfolds its full climate protection impact if renewable electricity is used to generate it. Green hydrogen is therefore the central element of the P2G&H concept approach.

According to the P2G&H concept, the operator commits himself to produce green hydrogen. The requirements for green hydrogen are currently regulated by law in §12i of the Renewable Energy Sources Ordinance in the version of July 14th, 2021

(BGBl. I, p. 2860). The electricity used must come from renewable power generation plants in Germany and be certified by the operator via certificates of origin. The use of renewable electricity minimizes the emission load of green hydrogen.

On European level, in addition to these requirements for green hydrogen, other quality criteria are required specifically for use as a fuel. According to article 27 of the Renewable Energy Sources Directive (RED II (2018)) the criteria for crediting are renewable origin, regionality (“geographical correlation”), temporal equality (“temporal correlation”) and additionality (“element of additionality”).

Purchase power agreements (PPAs) with spatially related and planned wind power or photovoltaic systems are particularly suitable for meeting those requirements, increasing acceptance and increasing regional added value.

The energy transition friendly operation of the electrolysis system brings additional added value for the overall energy system. Because climate neutrality requires sufficient controllable flexibility for the system integration of renewable power generation plants. According to the electricity market design study by the BEE (2021), electrolysers as a flexibility option in the consumption area can make a significant contribution to system and market stabilization in the future. The study confirms the feasibility of the energy transition goals with simultaneous increasing value creation in Germany. The central result is that the system-friendly use of up to 100 GW of electrolysis capacity can lead to an economic optimization of the entire system.

Taking into account the current power generation structure, the average GHG emission factor for Germany is around 400 g/kWh. If it is assumed that electrolysers are operated during hours with a high proportion of renewable energies, this results in an emission factor of around 275 g/kWh for these periods. In this case the operating times amount to 4,000 to 5,000 hours per year. Figure 10.2 shows the hourly emission factors. With the increasing expansion of renewable electricity generation, the emission factors will decrease. With a decarbonized electricity system or with a certified purchase of 100% renewable electricity, the emission factor is close to ”zero” The emission load of green hydrogen is then the lowest and the climate protection effectiveness through the substitution of fossil energies is highest.

“zero carbon ready” as a benchmark for maximized climate protection can be fulfilled by the electrolysers in the P2G&H concept. The P2G&H approch provides the necessary infrastructure for the flexible use of renewable electricity in a particularly efficient manner.

10.3.2 Climate-Neutral Heat Supply

Climate-neutral heat is a central component of the German climate protection goals. According to BMWK (2022), on the way to greenhouse gas neutrality by 2030, 50% of the heat should be generated in a climate-neutral manner. However, renewable energies for heat supply are limited, especially in the urban context. For this reason, mu-

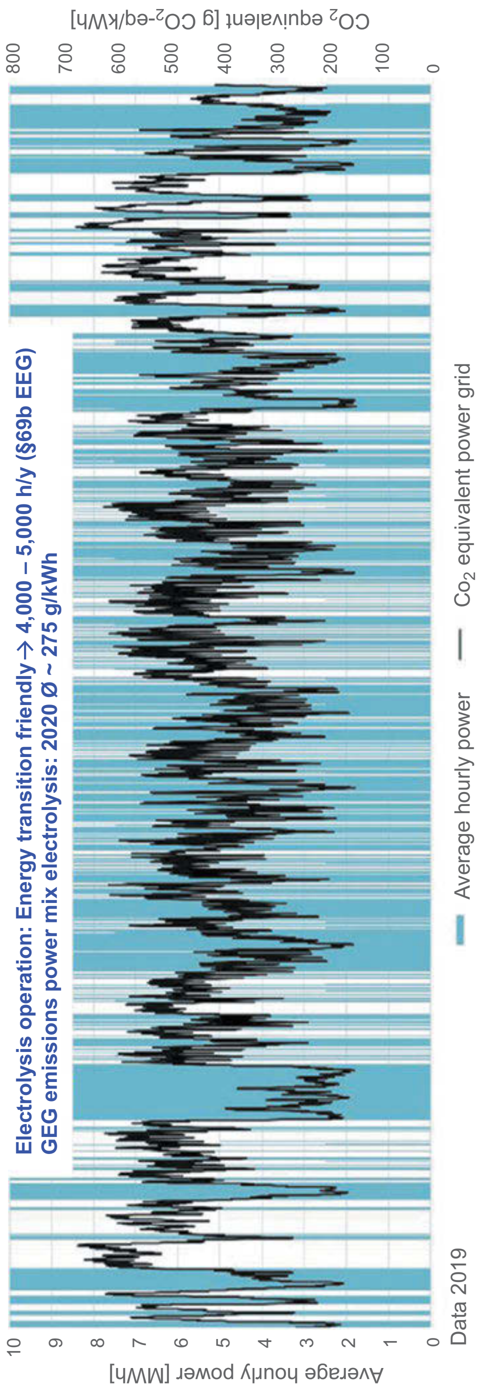

Figure 10.2: Emission load of electrolysis in energy-efficient operation.
(Source: Energy Charts Fraunhofer ISE 2022)

nicipalities are focusing more on waste heat potential, as this is classified as emission-free by definition (GEG (2020)).

Since 2020 Cities in Baden-Württemberg have been obliged to draw up municipal heating plans (KSG BW (2021)). The aim of this strategic planning tool is to show the measures for a climate-neutral heat supply. The company EGS-plan from Stuttgart was able to gain central insights from this process by developing more than 10 heat plans. The climate targets are locally achievable, but the availability of land for renewable heat sources in the urban environment is definitely limited or scarce.

In this context, the P2G&H concept approach enables the provision of emission-free waste heat from the production process of green hydrogen. The use of waste heat can relieve the pressure on undeveloped areas to use them for new energy infrastructures. A relevant aspect for the acceptance of the transformation of the heating system!

The green hydrogen generated with the P2G&H concept should not be used primarily for heat applications, since the greatest climate protection effect does not unfold here. In the building sector, heat pumps enable a much more efficient use of renewable electricity than the thermal utilization of green hydrogen in heating systems.

The ideal conditions for using waste heat are heat sinks that can be supplied with a temperature level between 60 and 65 °C that can be extracted of the electrolysis process. Concepts with high-temperature heat pumps are suitable for heat supply in existing buildings and for process heat in order to raise the electrolysis waste heat to the required temperature level.

10.3.3 Substitution of Fossil Energy

The biggest impact on climate protection and added value to the energy transition is achieved by using green hydrogen in sectors in which it is difficult to substitute fossil fuels through direct use of electricity. The higher the emission load of fossil energy use, the bigger the savings potential. The temporal development of the emission load of energy sources over the next decades plays a central role in the assessment of the reduction potential.

The transformation of the energy system requires the full exploitation of renewable expansion potential. After evaluating various studies (cf. IINAS 2020, Öko-Institut e.V. and Fraunhofer ISI 2015), a progressive reduction scenario for greenhouse gas emissions in the power grid is expected (cf. Figure 10.3, top). Starting from today's level, the GHG emission factor will drop from 400 to 20 g/kWh by 2050. In the P2G&H concept, electrolysis electricity is obtained in hours with a high proportion of renewable energies in electricity production and a low emission load (cf. 10.3.1).

The composition of the gas network will also change over the next few decades. While the emissions today – with mostly fossil natural gas – are still around 240 g/kWh (cf. GEG (2020)), they will be reduced by around 60% by 2050 through greater integration of renewable gases according to an evaluation by Dena (2018), Nitsch J. (2019) and various other studies. Compared to gas, hydrogen from energy-efficient electricity grid purchases has a lower emission load from around 2035 (see Figure 10.3, middle).

In the mobility sector – especially in long-distance trucks (heavy loads and long distances), diesel-powered drives (efficiency 40%) can be directly replaced by hydrogen-based fuel cell trucks (efficiency 60%). For many other mobility applications in the area of motorized and private transport as well as in public transport, the higher efficiency (90%) will continue to prove advantageous for the use of battery-powered electric vehicles. Figure 10.3 (below) shows the avoidable emissions that can be achieved by substituting the respective mobility systems. Diesel fuels or a fuel mix (50% diesel, 50% electric) have the highest potential.

Gray hydrogen can be directly substituted in the industrial and chemical sectors, which can be used to produce steel, glass and ammonia (cf. National Hydrogen Strategy 2020). Today, gray hydrogen is generated from natural gas using steam reforming with an efficiency of 60%.

Energy applications in the areas of mobility and industry are moving into the focus of H_2 utilization due to the highest impact in terms of climate protection. These can be seen in Figure 10.3, as they have a higher emission load than green hydrogen and thus lead to GHG savings in the case of an energy substitution.

10.3.4 Climate Protection Effects Beyond Urban District Boundaries

In the municipal context, the P2G&H concept unfolds its full contribution to climate protection, even beyond the urban district boundaries. In Figure 10.4, the emission loads from green electricity procurement are compared with the emission avoidance through waste heat utilization and hydrogen utilization in the respective sectors for a 1 MW_{el} electrolysis plant with 4,500 annual full utilization hours as an example. A usable share of 50% is assumed for the waste heat. Reference for the provision of heat are heat pumps with an annual performance factor of 3.3 and electricity from the power grid. The evaluations show the largest contribution to climate protection in H_2 utilization in the mobility (−470 t/a; −13 Tt/20a) and industry (−580 t /a; −15 Tt/20a). This means that the climate protection contribution of green hydrogen in industrial applications is almost twice as high as feeding it into the gas grid. These results are both scalable (x 10 at 10 MW electrolysis) and transferrable. In relation to the emissions from municipal GHG balances, the concrete savings potential of the P2G&H concept can be evaluated.

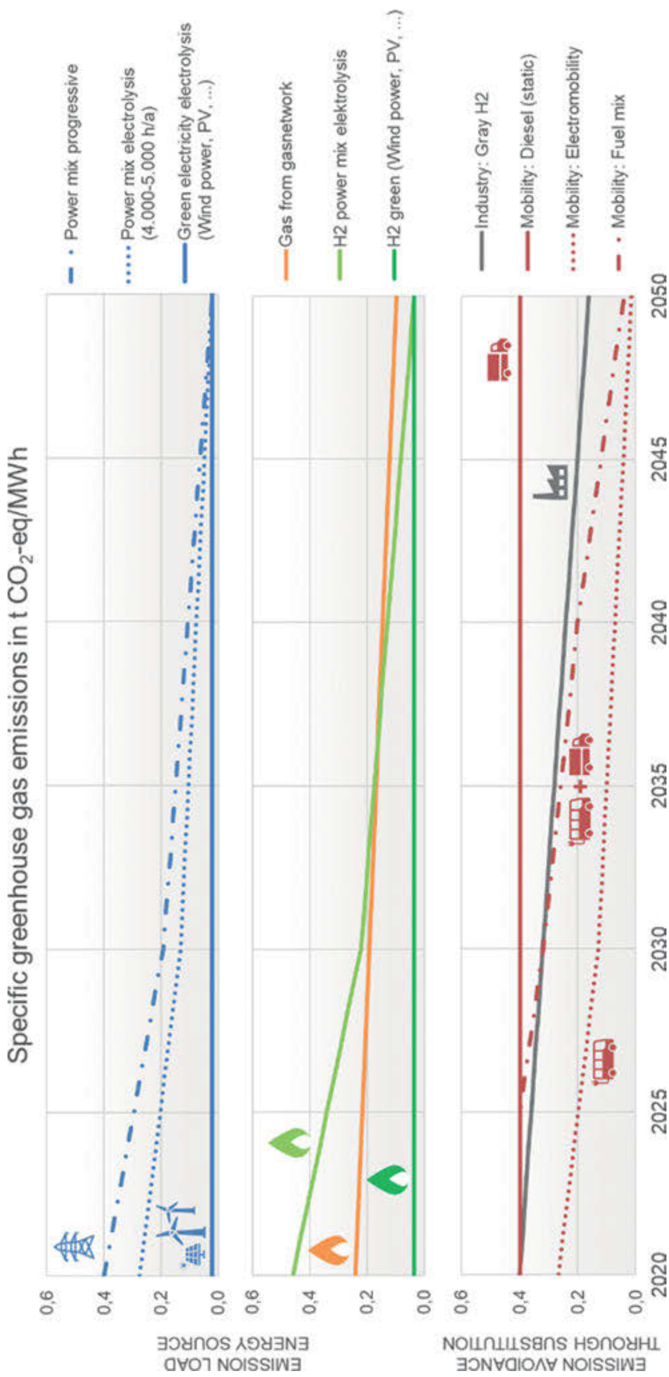

Figure 10.3: Development of GHG-eq of different energy sources and substitution paths.

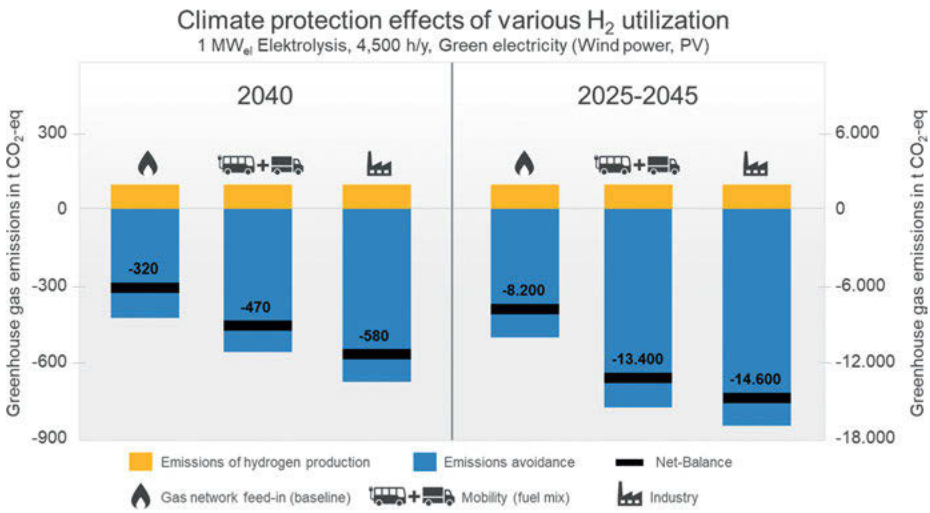

Figure 10.4: Climate effect of P2G&H ($1MW_{el}$) in municipal context.

10.4 Insights – Climate Urban District Neue Weststadt

The energy supply concept of the “Neue Weststadt” climate district in Esslingen follows the sustainable approach described in Chapter 10.2, which focuses on coupling the electricity, heat and mobility sectors on a local level (see Figure 10.5). The innovative centerpiece is a 1 MW_{el} alkaline electrolyser from Cummins, which converts around 5,000 MWh of renewable electricity into 85 t of hydrogen (Ø 250 kg/d, 2,800 MWh) per year and thus makes the energy storable. The green hydrogen generated at 11.5 bar is fed in to the city’s medium and low-pressure gas grid (0.85 or 0.05 bar) or for reseach purposes converted back into electricity in a bivalent combined heat and power plant from the company 2G (biomethane: 200 kW_{el}, H_2: 150 kW_{el}). The approach of H_2 production nearby consumers makes it possible to use the waste heat generated in the conversion process for the surrounding buildings via a local heat grid (600 MWh/a). A high thermal insulation quality of the multi-storey block development (approximately Effizienzhaus 55 standard) forms the basis for a low energy demand and high living comfort. The roof areas are consistently used to generate electricity using 1,400 kW_p photovoltaics. Together with electricity from biomethane combined heat and power plants, this is primarily used to supply the residents (tenant electricity and e-mobility) in order to achieve the highest possible ecological quality of the energy supply. A central energy management system controls the energy flows in the district.

In the climate district, the Green Hydrogen Esslingen GmbH (GHE) was established as a new operator structure out of the research consortium. In addition to the pure investment in the system, the company GHE is also the main applicant for the approval. Advantageous for successful operation are shareholders experience in handling gases (Stadtwerke Esslingen), skills in electricity market trading (Polarstern). In addition, system knowledge of the electrolysis plant is an advantage. Local electricity and gas grid concessions simplify further application procedures.

10.4.1 Planning and Implementation

In order to create a high quality of stay, hydrogen production in urban areas requires an integrated urban planning approach. For this purpose, an underground energy center was planned in Esslingen, in which the large system components were introduced via access openings. The basic requirement for the underground installation is also the spatial separation of hydrogen components (stacks, separators, gas purification, H_2 storage) from non-hydrogen components (ancillary units, control cabinets, electronics). This ensures that the normally fully automatic system could be put into a safe state from the outside in the event of a fault by a higher-level safety control system. With a sloping ceiling and an exhaust air tower at the highest point, the H_2 process room is also designed in such a way that no critical H_2 quantities can appear, even in the event of leaks. Emergency stop switches are also provided at various points in the energy center as a last safety measure in order to be able to override the autonomous safety chain if necessary.

The hydrogen production ("energy center") was separated from the adjacent technical center in accordance with DIN 4102 or EI 90 according to DIN EN 13–501 and has two independent escape routes with clear markings. In order to reduce constant noise pollution during operation, an additional silencer for the O_2 blow-out was taken into account and the recooling unit is placed on the adjacent building roof. According the P2G&H concept approach (see Chapter 10.2), the waste heat is not recooled, but mainly used to heat the buildings. In the current scale of 1 MW_{el} installed electrolysis capacity, the waste heat from the stack cooling is used directly with 250 kW_{th} at a temperature level of 60–65° C. This covers around 50% of the heat demand of the connected buildings (600 MWh/a in total). In addition, waste heat from the peripheral system components (rectifiers, inverters, transformers, low-voltage main distribution) can be brought to a usable temperature level using a heat pump. This results in a further 220 kW_{th} at ~ 65 °C, which also covers 25% of the heat demand. Together with the bivalent combined heat and power plant and an additional biomethane peak load boiler, full supply can be ensured all year round. In order to make the heat usable via a local heat grid, it was necessary to install low-temperature systems (surface heating) and fresh water stations on the building side.

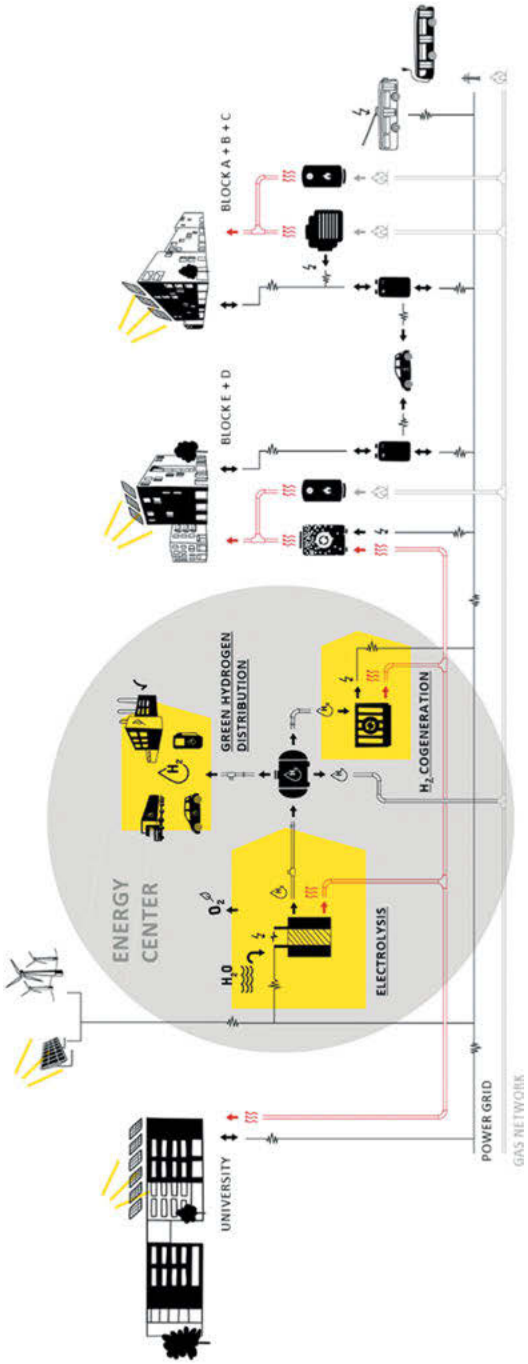

Figure 10.5: Energy concept climate urban district Esslingen.

During the commissioning process, the electrolyser was first tested at the factory (Factory Acceptance Test) – including all safety and functional circuits – and has a CE declaration of conformity. After installing the components in the energy center, an authorised inspection agency approved the system modules on the basis of the Ordinance on Industrial Safety and Health. In addition to explosion protection, this also applies to the function of the electrical installations, for example. All safety circuits were also subjected to a risk assessment (HAZOP). The functional safety and thus the probability of failure were classified using Safety Integrity Levels (SIL).

The running time of the electrolyser in operation depends essentially on the availability of renewable electricity. Since the PV electricity in the district is primarily available to the residents (tenant electricity and e-mobility), the PtG system mainly draws electricity from the grid from outside the district. In addition to the direct procurement of electricity from a nearby wind turbine, timetables specify the operating times for the procurement of green electricity by using forecasts of the electricity exchange price as an indicator for the share of renewable energies in the grid via an algorithm. The hydrogen is fed via a 180 m sand-laid DN 40 stainless steel line to a gas pressure control measuring system, where it is finally mixed with the city's medium and low pressure grid to decarbonize the gas grid (0.85 or 0.05 bar; max. 2.5 vol.%).

10.4.2 Approval of the Electrolysis Plant

The production of hydrogen by an electrolysis process in Germany generally requires approval under the 4th Federal Immission Control Ordinance (4. BImSchV). The relevant classification is carried out according to Annex 1 under number 4.1.12. and is clarified in a pre-application conference with the competent authority. After the classification, a procedure according to § 10 BImSchG with public participation must be completed and according to Art. 10 of Directive 2010/75/EU the electrolysis system is classified as an industrial emissions system. The operator must therefore compile an annual IE report on system operation (including measurements of water withdrawal, waste water and noise) for the responsible authority. Incidentally, the immission control permit has a concentration effect, i.e. it replaces all other permits that would be required for the system under public law (§ 13 BImSchG), e.g. the building permit, water law permit or the indirect discharger permit. In Germany, the responsibility for the implementation of the Federal Immission Control Act (BImSchG) is determined at the level of the federal states by the respective environment ministries. In Baden-Württemberg, the basic responsibility for the implementation of the BImSchG lies with the regional councils (RC).

In addition, based on the lower and upper quantity thresholds for H_2 and O_2, it must be checked whether a major incident permit is required in accordance with Annex I of the 12th BImSchV (major incident ordinance). In order to avoid this classification, the H_2 distribution concept in the project was designed from the start in such a way that the H_2 generated – after only brief and low intermediate storage – can be used immediately.

Figure 10.6 gives an overview of the actors involved in the approval process. On the one hand, the applicant for the project (GHE) bundles the technical planning of the individual disciplines and involves the necessary experts in the process. The leading authority (RC Stuttgart) involves the representatives of public interests as well as the public and ultimately grants the approval. In addition, the Esslinger pilot project also showed that a coordinative actor between all those involved enables ongoing close coordination with the authorities and can thus make a significant contribution to the success of the permit. The coordination is to be initiated by the applicant and was carried out in the project by the Steinbeis Innovation Center energieplus.

The scope, form, time of submission and preparation expertise of the required documents are to be discussed and defined with the authority in the pre-application conference. In addition to the general letter and the official forms, the following documents were submitted: process description, block flow diagram, plan representations, geotechnical report, building application, safety concept, preliminary assessment of mandatory EIA, fire protection concept, fire brigade plan, noise protection report, explosion protection concept, H_2 propagation calculation, checklist for the initial status report, list of pressure vessels and safety data sheets.

In the following, selected content-related information from the aproval procedure will be clarified.

In addition to the fire protection requirements under building law, early involvement of the local fire brigade has proven to be advantageous. In order to ensure adequate noise protection for the neighboring residents, specifications for silencers were specified for the building openings of the energy center. Due to the material properties of hydrogen and the risk of ignition when mixed with pure oxygen or air, a comprehensive safety concept was developed that works on different levels. The first internal level includes the internal monitoring of the electrolysis units themselves with emergency shutdown, depressurization of the hydrogen tanks and inerting of all connecting lines. The second level includes autonomous monitoring of the H_2 process and storage room. A permanent detection and fully automatic reaction to H_2 and O_2 in the air prevents the risk of an explosion before an ignitable mixture can occur. In a multi-stage safety chain, based on controlled mechanical ventilation, hydrogen production is switched off early and, if necessary, all hydrogen-carrying components are vented to the environment via a blower. This approach ensures that even in the event of a leak, the lower explosion limit (LEL) is not exceeded and a dangerous, potentially explosive atmosphere (geA) can therefore never occur. The third level includes protection against external influences. This includes monitoring of the supply air, triggering the above safety measures and switching off the entire system if smoke or fire is detected. The concept is structured in such a way that potential fire hazards from the adjoining block of buildings or the public space – for example from fireworks or cigarette butts – pose no risk to the system.

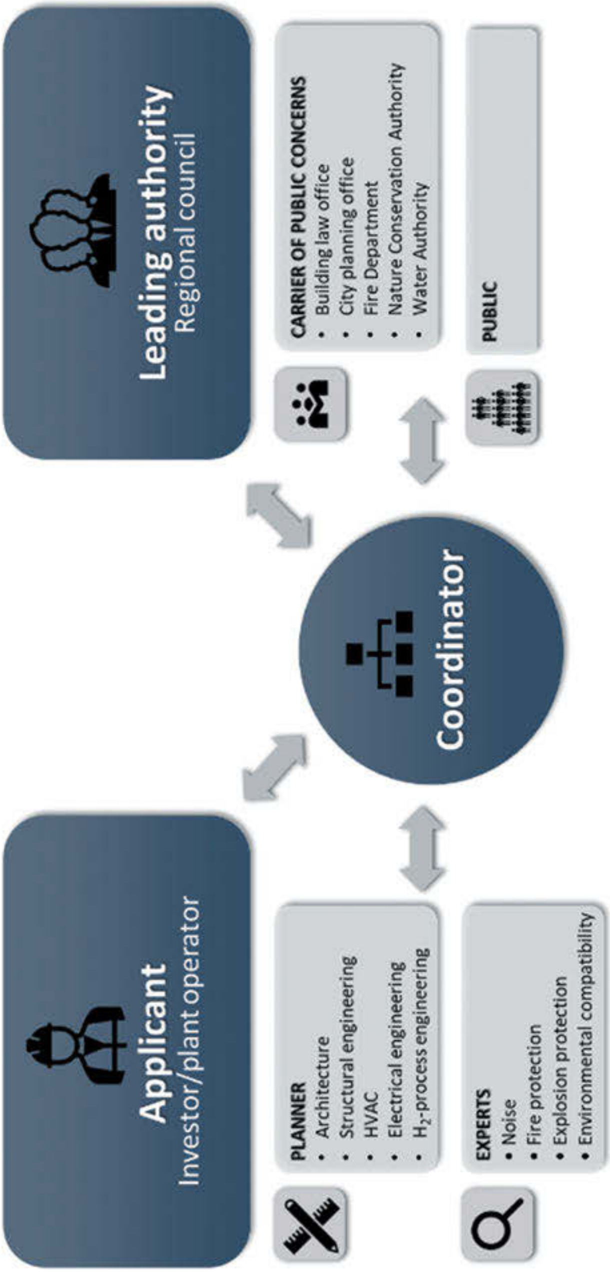

Figure 10.6: Actors Approval Process.

No further approval was required for the installation of the H_2 pipeline in the public space, as the operator holds the local gas network concession. The pipe routing had to be coordinated exclusively with the Office for Legal and Real Estate Affairs.

For the H_2 feed into the gas grid, a grid connection and connection usage contract as well as a feed-in contract must be submitted to the responsible gas grid operator.

10.5 Summary and outlook

Green hydrogen is a key element of the energy transition and essential for the decarbonization of the industrial and mobility sectors. With the P2G&H concept, green hydrogen is produced close to consumers in an urban context. Due to the use of waste heat and the short transport routes to the end user, this system approach is highly efficient. Heat consumers should have system temperatures below 65 °C for the use of waste heat, ideally with year-round heat demand. With this concept, existing districts with higher temperature requirements can also increase the waste heat temperature, e.g. using high-temperature heat pumps.

The climate policy goals of greenhouse gas neutrality require a high level of efficiency in the provision of emission-free energy sources in order to be able to realize the necessary electricity expansion volumes and to obtain the necessary social acceptance. The decentralized P2G&H approach, tested for the first time in the climate district of Neue Weststadt, shows the feasability and illustrates the value creation potential of this regional circular energy economy.

The path from the real laboratory to an established element of our energy infrastructure is predicted and must not be postponed further into the future. Among others, BEE (2021) clarifies that the current ramp-up of electrolysis plants must be pushed and promoted. “Firstly, this ensures a stronger market ramp-up, which lays the foundation for the high annual expansion rates for electrolysis in the decades to come. Secondly, this leads to an industrial-politically sensible, more equal expansion.” (BEE (2021))

The highest climate protection effect is achieved with the P2G&H concept through the direct substitution of fossil fuels. For this reason, the state of Baden-Württemberg is funding the construction of an H_2 pipeline between Esslingen and Stuttgart in the “H_2-GeNeSiS” project. This new marketplace for emission-free energy is intended to connect generation plants, such as electrolysis in the climate district, with large consumers of gray hydrogen in industry and diesel in the mobility sector (public transport, truck filling stations). Green hydrogen offers the perspective for a sustainable economic region.

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Holger Heible, Eva Michely

11 Developing Sustainable City Districts: A Practitioner's Report on Klimaquartier Neue Weststadt

Summary: On the site of Esslingen's former freight depot, RVI GmbH is developing 500 residential units and approximately 12.800 m^2 of business space. Since 2014, RVI has thus been responsible for a substantial part of Klimaquartier Neue Weststadt. Against the backdrop of an ambitious planning agreement, this essay discusses the challenges of sustainable project development from the investor's point of view. It seeks to complement the academic discourse with first-hand experience of sustainable building. In Klimaquartier Neue Weststadt, sustainable urban development takes place in a field of tension where attractive urban development, affordable rents and economic viability have to be kept in balance. In exemplary fashion, this essay highlights the special importance of the real estate industry for the process of decarbonisation.

11.1 Introduction

On the site of its former freight depot, the city of Esslingen is currently establishing a carbon-neutral city district. Called Klimaquartier Neue Weststadt, the new city district is part and parcel of Esslingen's ambitious goal of reaching climate neutrality by 2035. As one of thirteen interdisciplinary project partners in Neue Weststadt, RVI GmbH is developing 500 residential units as well as 11.300 m^2 of business space. Since 2014, it has thus been responsible for the realisation of a very substantial part of the Klimaquartier.

Based on the framework plan „Neue Weststadt", which had priorly been ratified by the city council's committee for technology and the environment, the selling price for the site was negotiated in the course of a tendering procedure. At the end of a rigorous selection process, RVI GmbH was awarded a sizeable chunk of the urban development in Neue Weststadt. This was the case mainly due to its willingness to accept the city's planning agreement, which contained a variety of stipulations that benefitted the council but had the potential to impair the economic success of the project.

By default, real estate development is a process that seeks to avoid unknown risks, especially if carried out by a middle-sized company such as RVI. At this early stage, the economic challenges of the project were difficult to calculate, especially since RVI had no prior experience of realising carbon-neutral buildings. Against this

Holger Heible, Eva Michely, RVI GmbH, Germany

https://doi.org/10.1515/9783110777567-011

backdrop, this essay seeks to complement the academic discourse on sustainable city districts with the investor's first-hand experience of developing and building Klimaquartier Neue Weststadt. Sustainable urban development takes place in a field of tension where attractive architecture, affordable rents and economic viability must be balanced against each other. In exemplary fashion, this essay highlights the special importance of the real estate industry for the process of decarbonisation.

11.2 Energy Transition in the Housing Industry

11.2.1 Actors on the German Housing Market

The heterogeneous landscape of actors in the German housing and real estate industry plays a significant role for the energy transition in general and the Klimaquartier in particular. Less than fifty percent of all dwellings in Germany are used by their owners; more than fifty percent of all residents, on the other hand, live as tenants. Lessors come in different guises, including housing cooperatives as well as institutions in the private and the public sector. However, the number of these corporate or institutional lessors is significantly smaller than the number of private landlords. According to a recent study by the IW, almost 14 million households in Germany pay rent to a private person, while 19 million dwellings are inhabited by their owners (Sagner 1). This ownership structure is of considerable importance for the energy transition in the real estate sector. Compared to private landlords and owners, portfolio holders have much more leverage when it comes to upgrading the energy performance of Germany's housing stock.

11.2.2 Placing the Project Developer

RVI GmbH is a real estate developing company that has been developing, building, and managing mainly residential property for almost fifty years. The residential units are sold to private investors who buy to let for profit. Based on the Act of the Ownership of Apartments (Wohnungseigentumsgesetz), they belong to the above-mentioned group of private landlords, letting their dwellings to RVI for at least ten years. During this period, RVI guarantees a fixed rental payment irrespective of occupancy rates or vacancies. As part of its service portfolio, RVI also takes care of the rental management as well as the administration of the property. While it thus continues to manage the properties it developed, RVI does not classify as a portfolio holder and concurrently has no say over refurbishments or retrofits. At the same time, it is in its own economic interest to develop a sustainable, durable product that fares well on the rental market.

According to Diederichs, project development consists in the combination of project idea, location, and capital to create profitable, competitive, and durable real estate projects (Diederichs 685). This definition finds complementation in Schulte and Bone-Winkel's more procedural approach. They focus on the coordinated interdisciplinary effort that goes into the planning and construction of viable buildings (Schulte and Bone-Winkel 29). Based on a rhizomic approach, RVI seeks to develop sustainable real estate projects that are tailored to the needs of their future residents while at the same time meeting the requirements of an investment product – that is, they must yield a certain trading profit. In this context, sustainability does not only refer to the buildings' energy performance but also to their durability and social as well as economic sustainability.

In the context of the research project in Klimaquartier Neue Weststadt, it was of crucial importance to understand project development as a dynamic process that underlies constant change. Serving as the blueprint for its real estate projects, RVI's Concept for Urban Living (Urbanes Wohnkonzept) is a developing approach that considers, and balances against each other, geographical, demographic, economic, architectural, technological, legal as well as social factors. Over time, the Concept for Urban Living has evolved into a non-hierarchical, rhizomic approach which was well suited to the challenges of the research project. It is mainly due to RVI's involvement in Klimaquartier Neue Weststadt that it now also responds to questions of energy efficiency and energy supply, sustainable building materials, mobility, and connectivity.

11.2.3 Energy Efficiency in Construction and Housing Stock

According to a DESTATIS press release, a total of 306,376 dwellings was completed in Germany in 2020, amounting to an increase of 4.6% compared to 2019 (DESTATIS 2021a). Following a downward curve between 2006 and 2009, 2010 marked the beginning of a steady increase in dwellings completed per year. From a total of 40.5 million units in 2010, the stock of dwellings had risen to a total of 42.8 million units by the end of 2020 (DESTATIS 2021b). This considerable increase underlines the assumption that in Germany, successful energy transition hinges on refurbishments and/or retrofits of the housing stock.

In this context, the decisive factor is not the ratio between newly constructed buildings and the housing stock but their respective energy consumption and performance. For instance, even if newly constructed buildings are carbon-neutral in operation, they might still come with a considerable carbon footprint due to their construction materials. According to the Climate Change Act, CO2 emissions in the German building sector must be reduced to 70 million tonnes by 2030. In 2019, the industry was still responsible for 118 million tonnes. This ambitious goal can only be achieved if energy efficiency improvements are carried out on the housing stock (cf. Die Bundesregierung). Therefore, it is our view that the insights gained in the research project on Klimaquartier Neue Weststadt should also be adapted and employed for the transformation of existing buildings.

11.3 Building Klimaquartier Neue Weststadt

According to the city of Esslingen, Neue Weststadt is the city's most important regeneration of inner-city space to date. Covering an area of ca. 13 hectares, Neue Weststadt formerly belonged to Esslingen's industrial cityscape and still bears testimony to the city's industrial heritage. Dating back to January 2012, the urban masterplan for the area resulted from an urban planning competition which was won by LEHEN DREI, a regional architectural practice. It encompasses the area known as Hengstenbergareal, named for a local manufacturer of preserved foods, the Neckaruferpark, which is to become an urban recreational area, as well as the site of the former freight depot which, amounting to 6.6 hectares, had been a wasteland since the 1990s.

Figure 11.1: Blocks B, C, and D (in construction).
(Source: Maximilian Kamps, Agentur Blumberg GmbH)

The former freight depot immediately borders on the urban structures of Neue Weststadt and is adjacent to the main train station as well as the medieval old town. To the south, the railroad tracks as well as the Neckar River bound the area. In the main, the site now consists of two sections, one belonging to the University of Applied Sciences and one comprising "LOK.WEST", the sustainable city quarter developed by RVI. LOK.WEST consists of a total of five residential and commercial buildings, three of which (blocks B, C and D) have been completed at the time of writing. In 2012, the partial area of the freight depot was awarded in a tendering procedure organised by the city council.

11.3.1 Tendering Procedure and Project History

In the tendering procedure for the freight depot, the future developer's idea and vision for the site were crucial for success. As opposed to a classic bidding process, the competition was not solely geared towards achieving the highest possible selling price for the site. Rather, it combined the selling price with a range of stipulations that were to guarantee the development of a vibrant city district characterised by a high architectural quality. At this point, the urban planning stipulations already included Prof. Dr. M. Norbert Fisch's 2012 project outline on renewable energy supply "Smart City – 100% erneuerbare Energieversorgung Neue Weststadt", which was to become the basis for the research project.

RVI's proposal pivoted around three perimeter blocks with spacious courtyards and five full storeys for the blocks B, C and D framed by two stand-alone buildings for the blocks A and E. In addition to optimised building envelopes, the energy concept foresaw photovoltaic installations on the roof surfaces to achieve maximum degrees of solarisation. For this reason, the perimeter block typology along with homogeneous roof surfaces appeared to be the most desirable architectural configuration. Unfortunately, these plans were thwarted by the architectural requirements of the council's planning agreement.

11.3.2 The Planning Agreement: Role and Remit of the Investor

From RVI's point of view, the signing of the planning agreement in June 2014 was one of the most important milestones in the project development. The planning agreement mainly concerns the following five fields of action:

- Urban development based on the urban masterplan
- Assurance of the urban development's quality and diversity
- Construction of a mobility hub for public transport
- Adherence to ecological principles
- Provision of infrastructure (mainly public streets and plazas)

One of the most important stipulations of the planning agreement concerned the district's climate neutrality. The energy supply structure for the buildings had to be such that the energy supply for heating, cooling, and electricity would be carbon neutral. Also, each of the buildings had to be certified by the German society for sustainable building (DGNB e.V.) to at least silver standard.

A further challenge of the planning agreement consisted in the provision of public infrastructure. Based on the German guidelines for planning competitions (Richtlinie für Planungswettbewerbe RPW 2013), multiple practices had to be commissioned for the planning of the streets and plazas in the area. The selection process then took place under considerable involvement of the public. The full importance of these particular stipulations, along with the investor's responsibility for the construction of the district's mobility hub, becomes clear when we consider their larger economic reverberations.

The relocation of responsibilities from the public to the private sector has an immediate influence on the project economy and hence on the developer calculation. From the investor's perspective, it can be regarded as a de facto increase of the land price which by extension predicates an increase in construction costs. This has had consequences for the research project because it limits the budget for experimental building equipment. It is of equal relevance in a social sense that it also leads to an increase in rental prices.

11.3.2.1 Research Project vs. Realisation Pressure

Originally, the acquisition of the area in 2014 was part of a medium-term earnings calculation which required that block B, the first of the five RVI buildings, be completed in 2017. The project development foresaw a one-year iterative planning process during which the development rights and the planning permission were to be obtained as well as a two-year construction period. The construction of blocks C and D was to follow a two-year rhythm, with completion being achieved in 2019 and 2021 respectively. This rhythm was pertinent as the three blocks B, C and D amount to approximately 80% of the development's floorspace.

In February 2018, the thirteen project partners signed the research project's cooperation agreement; the funding for the research project was granted by PT Jülich in December 2018. If the cooperation agreement had been signed based on a preliminary project proposal, ideally as early as 2015, a physical connection of all blocks through a comprehensive supply network might have been possible. As it is, this can only be realised for blocks D and E, mainly due to the diverging schedules of the project partners. The need for an integrated approach to the planning process, especially when representatives of the public and the private sector are harnessed to achieve a greater goal, should be kept in mind for future projects.

11.3.2.2 Economic Efficiency: Pricing Block B

In the private sector, every decision for or against a real estate project hinges on its anticipated economic success. The mathematical method for the determination of economic success in housing companies consists in an evaluation of economic efficiency; the equivalent for a project developer such as RVI consists in a so–called simple developer calculation. These calculations are based on a simple rule of three – in the free market economy, business companies will not and cannot compromise their own criteria for marginal returns. In both methods, any increase in land prices, building costs or incidental building costs have immediate effects on both the selling and the rental prices. Depending on the investment volume, the anticipated trading profit automatically determines the rental prices in the developer calculation.

In 2017, RVI conducted an analysis of the influence of the planning agreement on the selling and rental prices of block B. The analysis was carried out based on reference data from earlier projects as well as the cost controlling of the ongoing building measure. In particular, the analysis considered the cost brackets 100–200, 400 and 700 as defined in the German Industrial Norm (DIN 276) on Building Costs – Part 1 Building Construction. In these four cost brackets, 100 – site, 200 – provision of infrastructure, 400 – building equipment, 700 – incidental building costs, the planning agreement's stipulations are evidenced most clearly.

In cost bracket 100 (site), the financial burden of the mobility hub and the provision of public streets and plazas is extremely tangible. It accounts for extra costs of ca. 146 EUR for each square metre of gross floor space, almost doubling the land price for each square metre of gross floor space. A similar picture becomes visible in cost bracket 400 (building equipment). Compared to a RVI reference project, the costs for building equipment and fit-out (including the photovoltaic installations) nearly double and amount to extra costs of 173 EUR per square metre of gross floor space. This increase is solely caused by the goal of carbon neutrality.

Cost bracket 700 (incidental costs) sees an increase of 93 EUR for each square metre of gross floor space compared to a RVI reference project. This is mainly the case because RVI projects tend to be planned in–house, causing no comparable planning/design costs. Additional costs for the energy concept, the research project, the DGNB certification process as well as the obtention of development rights are also contained in this cost bracket.

In summary, the cost brackets 100–700 amount to a total construction cost of 2,230 EUR per square metre of gross floor space in block B. Of this total sum, 412 EUR or 18.5% result directly from the stipulations of the planning agreement. Looking at the rental prices, this entails an increase of 2.69 EUR or 26% per square metre. The monthly net rent thus rose from 10.17 EUR to 12.86 EUR per square metre living space.[1] The additional costs relating to the research project amount to approximately 180 EUR per square metre (excluding the funding) and result from building equipment and specialised engineering. Thus, only 44% of the additional construction costs stem from the research project.

11.3.3 Carbon Neutrality in Operation: Blocks B, C and D

According to the definition used in the research project, all RVI buildings are carbon neutral in operation: CO2 emissions for housing and mobility per head and year are

1 According to ImmobilienScout 24, the comparison rental price for newly constructed buildings was between 10.71 EUR and 10.86 EUR per square metre when block B was completed in 2017.

below 1 tonne. However, mainly due to the time lag between the beginning of construction and the launch of the research project, the energy supply for blocks B and C differs in significant ways from block D.

Blocks B and C feature identical installations. They achieve carbon neutrality through the combination of biomethane cogeneration units, gas peak boilers and the extensive use of photovoltaic panels on the roof surfaces. In a system called “Mieterstrom” or “tenants’ electricity”, the locally generated solar power feeds directly into the buildings’ power grid. These installations belong to the buildings’ common facilities and are thus in the possession of RVI’s private investors i.e., the community of apartment owners according to the Act on the Ownership of Apartments. The electricity market in Germany is subject to complex regulation which makes the cooperation with an energy contractor desirable. It is also advantageous from an administrational point of view: If the community of apartment owners itself sold the electricity to the residents, acting as a de facto energy provider, it would have to declare taxes on its earnings. This would then complicate the administration of the property to a significant degree.

The energy concept and installations of block D as well as the linkage of the building’s infrastructure with the district’s energy centre will be detailed elsewhere in this volume. Suffice it to say that, as opposed to blocks B and C, the photovoltaic installations in block D are owned and operated by Green Hydrogen Esslingen GmbH (GHE) who also act as energy contractors in the classic sense. This means that the community of apartment owners are not involved in the energy supply of the building. In the case of block B and C, the public funding available for the installations was returned to the granting body: Because the ownership of the buildings’ common facilities passes from RVI to the community of apartment owners once the buildings are completed, it would have been uneconomic as well as legally complex to draw on the funding.

11.4 A Practitioner’s Recommendations

Considering the heterogeneous landscape of actors in the German housing and real estate industry, the importance of reliable partnerships cannot be overrated. The decentralisation of energy supply structures is a relevant factor for the energy transition in the housing sector and it hinges on professional management. To achieve carbon neutrality in the blocks B, C and D, the implementation of tenants’ electricity was paramount. Due to the regulative complexities of the German electricity market, it would hardly be feasible for a lean, middle-sized project developer such as RVI to wear the additional hat of energy provider, selling locally generated solar power to the consumer. While it was evident from the beginning that RVI would have to partner with a professional provider of tenants’ electricity, finding this partner was still an onerous task in 2016. At the time, Polarstern Energie was one of a handful of pioneers in the field.

Urban planners need to put a stronger priority on urban sustainability. The research project in Klimaquartier Neue Weststadt spotlights the fact that a variety of stipulations in the planning agreement might detract economic resources as well as attention from the overarching goal of inner-city carbon neutrality. Based on the urban masterplan for Neue Weststadt, the ideas of the urban planning authorities were cast in stone, sometimes with consequences for both the local housing market as well as the research project. For instance, the council's insistence on a heterogeneous roofscape collided with the developer's wish to establish homogeneous roof surfaces to optimise the use of photovoltaic panels.

Finally, the space requirements for the technological fit-out and equipment, such as the subterraneous energy centre containing the electrolyser, should be analysed, and determined early in the planning process. The construction of subterraneous inner-city space is not only cost-intense, but it also competes with the legal requirements concerning the provision of a certain ratio of parking spaces per dwelling. These requirements, dating back to the 1970's romanticised notion of a car-friendly city, are in urgent need of revision.

11.5 Conclusion

For a middle-sized business such as RVI, the economic risks involved in a research project on sustainable city districts were considerable. The diverse demands of the planning agreement as well as the cooperation with an interdisciplinary team of twelve project partners required the willingness to invest more resources than usual and to deviate from the project timeline and budget if necessary. It further required the willingness to raise both the selling and rental prices at the company's economic risk. The decision to accept and tackle these challenges was based solely on the motivation to assume responsibility for the housing industry's carbon footprint.

As evidenced above, there cannot be one single recommendation for the realisation of sustainable real estate projects. In our view, the willingness to tolerate ambiguities is crucial for success: Practitioners in the field, architects, engineers, developers, construction companies and city councils, need to be open to emerging technological solutions and their implementation. A holistic approach to sustainable project development might also entail a deviation from the economic premises of a real estate investment. Klimaquartier Neue Weststadt provides proof that the carbon-neutral operation of residential and commercial buildings can be achieved at competitive prices without compromising their architectural quality. This report hopes to dispel the reservations against the necessary changes in the way real estate projects are developed, built, and manged in Germany.

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Alexander Müller-Dollinger, Mathias Oberhauser, Martin Neuburger, Walter Czarnetzki

12 Design of a Mobility Infrastructure in the Urban District with Special Consideration of the Public and Private Charging Infrastructure and the Expansion of the Bus Overhead Line Network

Summary: The mobility concept for Esslingen's Weststadt comprises three pillars: Expansion of the overhead line network of the municipal transport services with the district, use of battery electric vehicles in the public and private sector and the use of hydrogen vehicles in a car sharing fleet. In order to make an expansion recommendation for Esslingen's overhead line network, the required traction and transformer capacities were simulated during the course of the project and the results validated with real measurement data. In this way, it was possible to map the entire line network of Esslingen's public transport services. For the design of the public and private charging infrastructure, solution approaches were developed in the project network and design tools for cities and municipalities were developed. With the help of these tools, the design of the charging infrastructure should be simplified and the expansion of charging stations in Germany should be accelerated. The "Verein für emissionsfreie Mobilität Esslingen (EME) e.V." was founded to activate the market for hydrogen mobility.

12.1 Challenges

Elimination of local and global emissions is the decisive challenge in the implementation of new mobility concepts. From a technical point of view, although there are many possible approaches, only a solution that is economically viable for civil society as a whole is also sustainable in every respect. An economically viable solution means providing energy, including for mobility, within the current cost structure. Although it has been shown that renewable energy sources can supply electrical energy at low cost (Roser 2020), the demand for mobility in particular is decoupled in terms of time and place.

One aspect that is very often neglected in the public discussion is that energy storage systems mean that the installed power only has to cover the average demand and

Alexander Müller-Dollinger, Mathias Oberhauser, Martin Neuburger, Walter Czarnetzki, University of Applied Sciences Esslingen, Germany

https://doi.org/10.1515/9783110777567-012

not the peak capacities (Sterner 2010). The installed power can thus be many times lower than in the case of energy concepts without storage. In addition to reducing costs, this also results in a reduction in land and resource consumption. The implementation of an energy storage system or an energy carrier is therefore unavoidable.

Due to high material input and resource consumption, batteries are only indicated in limited applications. The smaller the vehicle and the shorter the average distances, the more sense it makes to use batteries. Long-haul freight transport is not feasible with battery-electric commercial vehicles.

In the present overall concept, hydrogen was selected as the energy carrier and energy storage medium. The implementation shows that it is ideally suited in sector coupling. Supposed efficiency losses can be compensated for by use in the heat sector. With mobility, the advantages of rapid filling and also the use of waste heat in the vehicle come into play.

12.1.1 Overall Concept

Mobility is an important need of today's society, and can only be satisfied by a considerable expenditure of energy. In recent years, for example, about a quarter of Germany's total primary energy consumption took place in the transport sector. Of this, around two-thirds was needed in passenger transport. An overall energy concept for an urban district must therefore also take into account the mobility needs of the residents. Within the framework of the overall concept developed, the mobility sector is thus an important building block. The development of energy coupling is indispensable for the success of the transformation of our society's energy supply.

In addition to reducing mobility needs through the provision of supply infrastructures in the neighbourhood as well as shifting fulfilment of demand to local public transport (LPT) through good connections and a broad and demand-oriented offer, the provision of individual mobility solutions is indispensable. In doing so it is also important to ensure that land consumption caused by individual transport does not continue to increase. A shared use option for passenger vehicles was thus also implemented in the mobility concept.

It is crucial for all solution approaches that they not only eliminate emissions locally, but also bring about a significant reduction in emissions globally. Electric drive technologies can achieve this, at least locally. This nevertheless requires a sufficient supply of electrical energy. With stationary applications, sufficient cabling makes this possible. With mobile applications, however, cabling is only possible with a correspondingly high expenditure, as can be seen in the example of overhead lines for electrified rail transport.

12.1.2 Implementation Example: Car Sharing with Hydrogen Vehicles

One of these additional offers will be a station-based car sharing scheme for the residents of the urban district. The mobility data was collected as part of a household survey in the urban district. The survey was conducted by the Berlin Institute for Social Research (BIS) on 13.02.2022. In total, residents from 40 flats took part. 40% of respondents stated that they are interested in a car sharing model. The desire for vehicles with a long range (> 400 km) was mentioned in particular. The survey also showed that just under 50% of respondents have driven an electric car so far. This makes it very important to support the market ramp-up of battery electric vehicles and especially hydrogen vehicles and to make the new technologies accessible to the users. The leasing rate for a hydrogen vehicle is very high (Comparison: Hyundai Nexo 1300 Euro per month, annual mileage 40000 km).This high cost would be reflected in high base and tariff fees and thus not contribute to the activating the hydrogen vehicle market. In order to nevertheless boost the economic incentive of car sharing with hydrogen, it is necessary to develop further strategies and corresponding tariff models with which the mileage of the vehicles can be increased and thus the total costs per kilometre minimised. This can be achieved by allowing different users, who each accumulate only a low annual mileage, to access a vehicle together. In particular, use in an operating fleet by industrial customers is targeted. The business model of the requested car sharing companies initially envisaged a fixed anchor tenant. An anchor tenant is an entity that undertakes to purchase a fixed quota of runs each year. This entity could, for example, be an authority, a company or even a private person. To get closer to this goal, the "Verein für emissionsfreie Mobilität Esslingen (EME) e.V." was founded in May 2021 under the leadership of Prof. Dr. Walter Czarnetzki and Alexander Müller-Dollinger. The aim of the association is to make zero-emission mobility accessible to the population, with a special focus on the use of hydrogen. The association was successfully registered as an economic association in September 2021 at the Stuttgart District Court (registration number VR 725208).

Within the framework of an economic feasibility study, a planning tool for the design of a car sharing fleet was developed. It is intended to make it easier for future associations/organisations to build up a fleet of vehicles. The following parameters were taken into account: leasing rates, users/association members, user distribution, vehicle utilisation and the tariff model. The tariff model is the decisive factor for whether a hydrogen vehicle is booked or not. For example, a hydrogen vehicle must be cheaper over longer distances than a battery vehicle, for which the hourly tariff is cheaper per se. In order to arouse interest among companies and public authorities, a maximum kilometre price of 38 cents/km for the hydrogen vehicle is also being aimed for. This amount is based on the commuter allowance and thus also creates incentives to use the car-sharing model for business trips. This is intended to ensure that the battery vehicle is used for shorter distances, while the hydrogen vehicle is used for longer distances. Vehicle utilisation is an important parameter for economic efficiency here. For battery electric vehicles, the charging time must be taken into consideration. Thus, for the economic efficiency calculation, vehicle utilisation for battery electric vehicles is given as < 50% and for hydrogen vehicles as < 80% (Assumption from the course of the project after consultation with several car sharing providers). Hydrogen vehicles thus have a significant advantage over battery electric vehicles.

12.2 Private Charging Infrastructure

In addition to the public charging infrastructure in the urban district, private charging infrastructure in underground garages was also designed and installed. When it comes to dimensioning the charging stations and transformer sizes in urban districts, it is recommended to derive the required charging capacities from the charging behaviour and the requirements of the users for a modern and individual charging infrastructure. Within the framework of the project, a charging profile generator was developed to support municipalities and cities with the design of the private and public charging infrastructure. The planning tool works as a standalone application and can be purchased free of charge from Esslingen University of Applied Sciences.

The mobility data was collected as part of a household survey among the residents [of Esslingen's climate district "Neue Weststadt"] conducted by the Berlin Institute for Social Research (BIS) on 13.02.2022. The survey showed that 80% of the residents park their vehicle at home by 8 p.m. and need it charged up again by 7 a.m. in the morning. 90% of respondents stated that they travel less than 50 km per day by car. The survey also showed that users do not want to charge their vehicle every day. Users were then classified into three user groups: users who charge on a daily basis, users who charge twice a week and users who charge their vehicle only once a month. Another uncertainty factor alongside charging behaviour is the vehicle fleet and the user group. In this study, we succeeded in developing a planning tool that considers different vehicle segments. It should be emphasised that different vehicle types are simulated and no average values are considered. The proportion of small vehicles (12 kWh/100 km) is thus given as 20%, the proportion of mid-range vehicles (17 kWh/100 km) as 55% and the luxury class (23 kWh/100 km) as 25% (Wörner/Blesl/Jochem et al. 2019). In addition, frequent drivers (120 km/day) are reported as 20% and average drivers (40 km/day) as 80% according to the survey. The planning tool also shows a savings potential using different load management strategies. Cascade control was implemented here for the purpose of optimisation. The potential for peak load optimisation by means of load management is 40%. This makes it possible to reduce transformer sizes and thus increase economic efficiency.

12.2.1 Methodology

The correct dimensioning of the connected load has a significant influence on ensuring safe and reliable charging. The following must therefore be taken into account in planning:

- the type and number of vehicles expected for the respective location
- the charging power of the vehicles to be connected
- the expected average parking time
- the charging behaviour of the vehicle owners

The following (Figure 12.1) is a schematic representation of the underlying simulation structure.

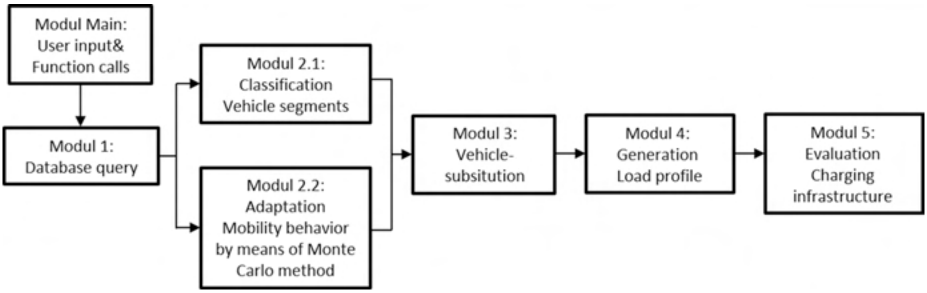

Figure 12.1: Simulation structure.

The variability of these influencing factors is very high and makes it difficult to specify guideline values for the number of charging points and the charging capacity to be installed. A stochastics method is used to represent the variability of the influencing factors “parking time” and “charging behaviour of the vehicle owners” as realistically as possible: the Monte Carlo simulation, which is based on a very large number of similar random experiments. It attempts to solve problems that cannot be solved analytically or can only be solved with great effort numerically with the help of probability theory. The arrival times are varied using standard deviation and the influence on the maximum charging power is investigated (Figure 12.2). Figure 12.3 shows the maximum charging power for 20 charging points with a charging power of 11 kW as a function of the period under consideration for a standard deviation of 0.5. Varying the arrival times results in different connected loads at the transformer for each day. In this example, it will be shown how the transformer power can be estimated for an average daily fleet consumption. The average daily fleet consumption is given as follows: small vehicles 20 km, mid-range vehicles 40 km and luxury class 120 km (Assumption from the course of the project). In order to estimate the maximum charging power, the simulation length must be increased until the maximum power does not change between days. A period of 100 days is considered sufficient to represent the maximum charging power (deviation approx. 2 kW = 2%). This method is useful to design the maximum connected load for a charging infrastructure and thus determine the transformer size. Furthermore, this method is useful to estimate how often the selected scenario occurs. In the case of Esslingen's Weststadt, this occurs with a high probability after 100 days.

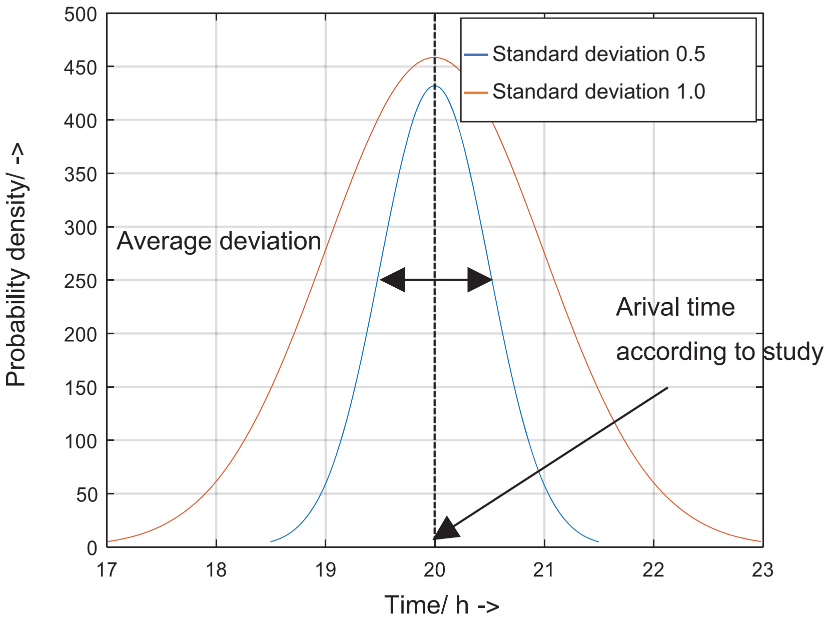

Figure 12.2: Probability distribution.

12.2.2 Design of the Required Charging Capacities

When dimensioning the charging power of a charging point, it is important to know what percentage of the expected charging processes can be carried out with which charging power. For this, it is crucial to know when the users park the vehicle and by what time they need it charged up again. This data was obtained from the household survey. At this point, an additional criterion is introduced: The "dynamics" (Table 12.1) describes whether and how often a charging process can be shifted in time.

Based on this value, an estimate can be made regarding the charging capacities to be installed. It can be seen that 100% of the charging processes for an average daily mileage of 40 km can be carried out with a charging power of 3.7 kW (Figure 12.4). However, it can also be seen that only 40% of the charging processes would be possible for full charging with 3.7 kW. From a charging power of 11 kW, 97% of all charging processes can already be carried out (Figure 12.5).

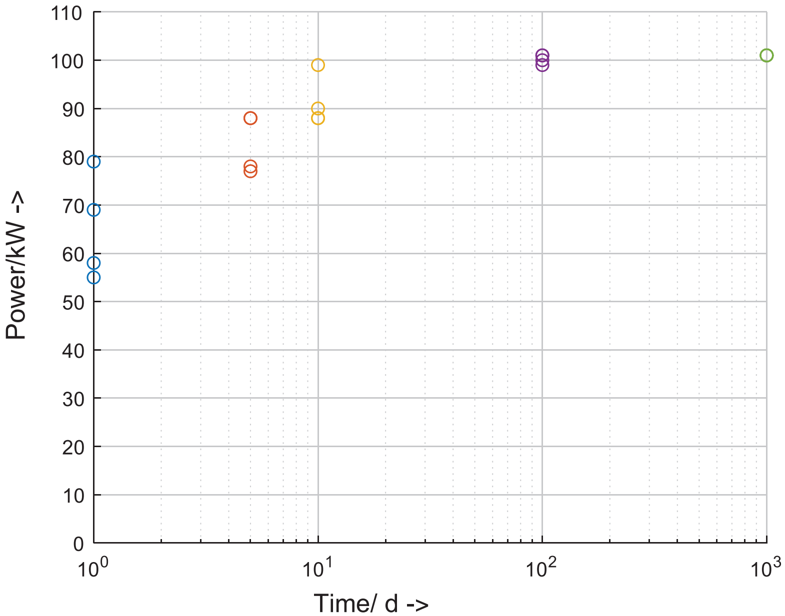

Figure 12.3: Influence of the maximum charging power of 20 charging stations a 11 kW depending on the simulation time. Average daily mileage: small vehicles 20 km, mid-range vehicles 40 km and luxury class 120 km (Charging behaviour from Frenzel/ Jarass/Trommer et al. 2015).

Table 12.1: Definition of the “dynamics” criterion.

Dynamics	Meaning
< 1	Charging process not feasible
1	No time-shift possible
2	Time-shift possible once
3	Time-shift possible twice

12.2.3 Reduction of Peak Load by means of Load Management

Based on the discrepancy between a vehicle’s parking and charging times (“dynamics” > 1), it is possible to optimise the charging processes and reduce the peak load. This can be implemented by means of a load management system. Figures 12.6 and 12.7 shows how the planning tool works. Assuming that 20 vehicles are being charged up at a private charging station in the urban district with a maximum charging power of 11 kW, the algorithm attempts to use cascade control to shift the charging processes with regard to the lowest possible maximum power. For Esslingen Weststadt district, the maximum connected load can be reduced by 40% by using a load management system.

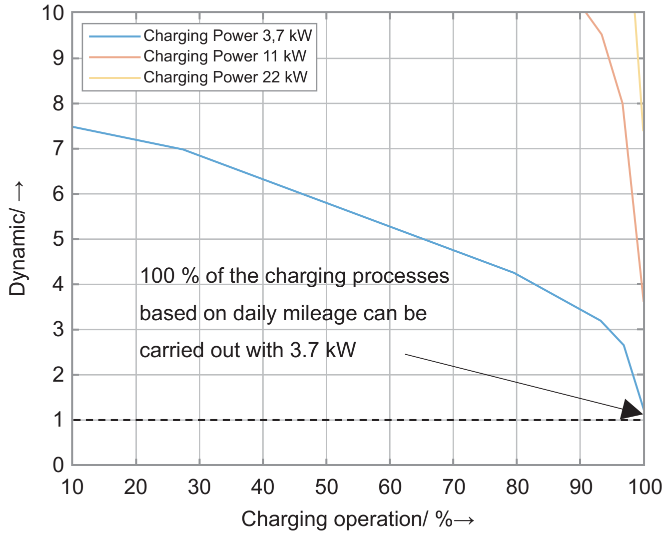

Figure 12.4: Temporal dynamics of the charging processes from the questionnaire; "Average daily mileage of 40 km". Data collected by BIS.

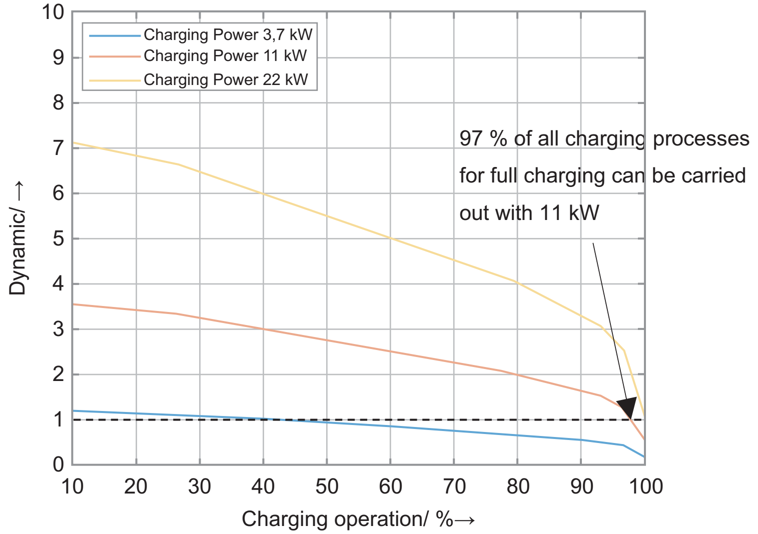

Figure 12.5: Temporal dynamics of the charging processes from the questionnaire; "full charging of 250 km". Data collected by BIS.

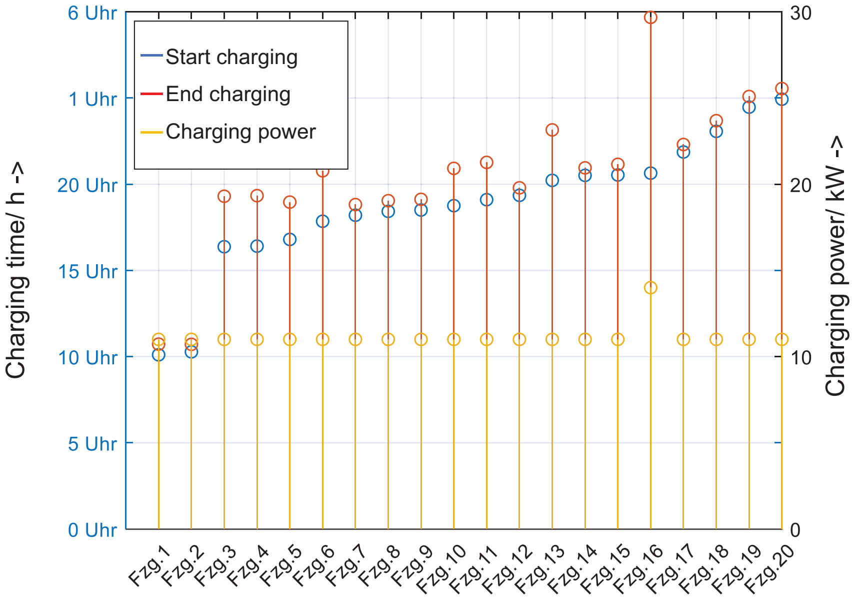

Figure 12.6: Charging profile, simulation duration 2 days, charging profile based on frequency distribution (Charging behaviour from Frenzel/Jarass/Trommer et al. 2015).

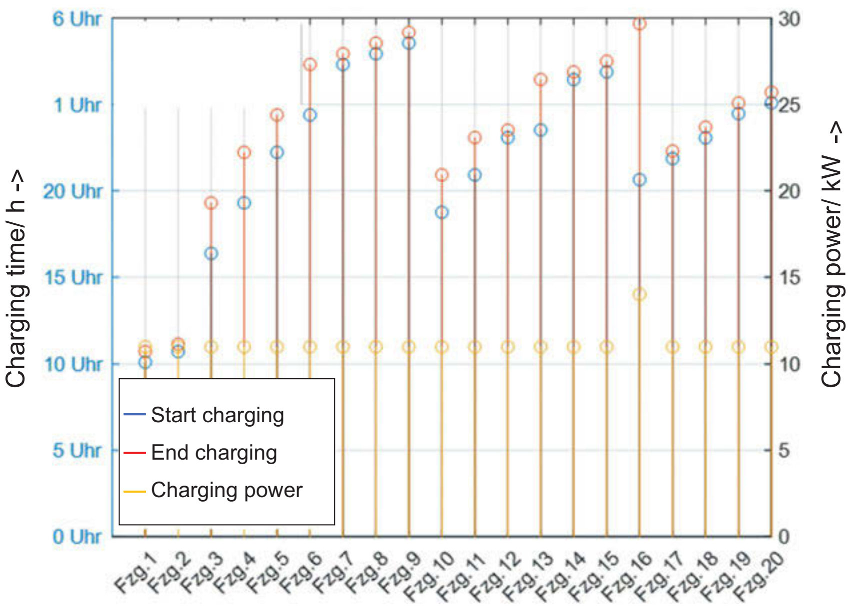

Figure 12.7: Charging profile, simulation duration 2 days, charging profile based on load management (Charging behaviour from Frenzel/Jarass/Trommer et al. 2015)..

12.3 Esslingen's Overhead Line Network

Local public transport is a very important component of modern mobility concepts in an urban environment. While in large cities local transport is usually provided by a combination of suburban or underground trains with a supplementary range of bus lines, in medium-sized cities such as Esslingen am Neckar, city buses and trams are predominant. The use of trolleybuses in regular urban transport has a long historical tradition in Western and especially Eastern Europe. In West Germany, however, almost all trolleybus networks were abandoned in the mid-1970s as a result of the politically desired promotion of diesel technology. However, the Esslingen Municipal Transport Company (SVE) retained two fully electric lines with a current total length of 30 km in its 175 km route network with a total of 360 stops (Figure 12.8).

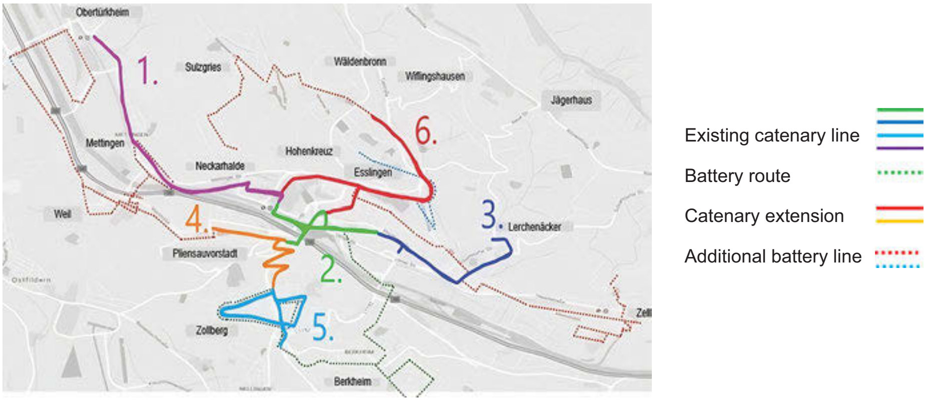

Figure 12.8: Route network.

The continuously electrified main line (1,2,3 in Figure 12.8) runs along the Neckar from Oberesslingen to Obertürkheim. The second line (line 5), which was created from a former tram line, reaches the suburb of Berkheim with some considerable gradients. Even more so than the main line, this line has one-way sections (. . .. outward and return paths take different streets, one-way). SVE pioneered the introduction of the world's first electric hybrid bus line in 2016. This new type of bus can charge its traction battery on sections of the existing lines (2 and 5 in Figure 12.8) and run the remaining sections – previously operated using diesel buses – without overhead wires by using the stored energy. Sections previously only travelled in one direction can now also be travelled in the opposite direction. Thanks to specially adapted battery size and maximum charging and discharging power, the In Motion Charging concept (IMU) used here allows continuous driving without the additional charging times needed with other types of battery buses.

After this concept successfully proved itself in everyday operation on the new line for five years, the city of Esslingen set itself the target of operating the entire route network with zero-emission electric hybrid buses by 2024. Thanks to the significantly increased battery sizes of the second generation of these vehicles compared to the first generation, only a very moderate expansion of the overhead lines by 5 km or 16% is required for this transport service.

12.3.1 Example for a Pilot Run (Neckarhalde – Main Station (ZOB))

Computersimulation is a very powerful tool to optimize system design in a very early stage. In the field of longitudional dynamics of vehicles like battery electric, electro-hybrid, diesel-hybrid or fuel cell busses first a so called pilot run has to be done. For the pilot run a GPS sensor was installed on the roof of the diesel bus. It measures position, speed, acceleration and height of the bus as a function of time with a frequency of 10 Hz. In addition a video camera has been installed. Main purpose of that video is to find out later why a bus has stopped. It might be because of a red traffic sign, a pedestrian crossing the street, traffic jam or because the bus stopped at a regular bus stop. It is helpful to later rework the measurements because all positions of the bus can be restored.

After the pilot run an offline simulation was done using the measurement results from that run. A modell of the bus type under consideration – in our case the electro-hybrid bus – tries to follow the pilot run. Because the mathematical model represents a „white box“ of the bus much more signals can be stored as during pure measurement drive. The signal quality of course highly depends of the model and its parameters.

During the second stage of development of Esslingen city bus network, after the city parlament decided to realize full electric operations till end of the year 2024, the focus was on infrastructure. The length of the catenary sections and battery sections was optimized. The length of the catenary section has to be long enough to be able to fully charge the battery till its end and the length of the battery section should not be too long in order to avoid to reach minimum state of charge before reaching the catenary again.

Figure 12.9 shows the measured and simulated battery state of charge for a downhill drive from a suburban end station called Neckarhalde down to the main station. The total height difference is approximately 160 m.

The bus has reached the station after pure battery drive with a remaining state of charge of 62%. The pilot run has been done purely with battery. After calibration of the model the simulated SOC was close to the measured SOC as long as no catenary was assumed. As it can be seen the SOC was even increasing at station Krummenacker and then slightly decreasing till station Sankt Bernhard/Flandernstrasse, the end of the future battery line. From that station on connection to a catenary was simulated. Therefore the simulated state of charge was increased by loading from catenary to more than 90% at the end of the line but the measured state of charge (without catenary) was decreasing to under 50% at the end of the line.

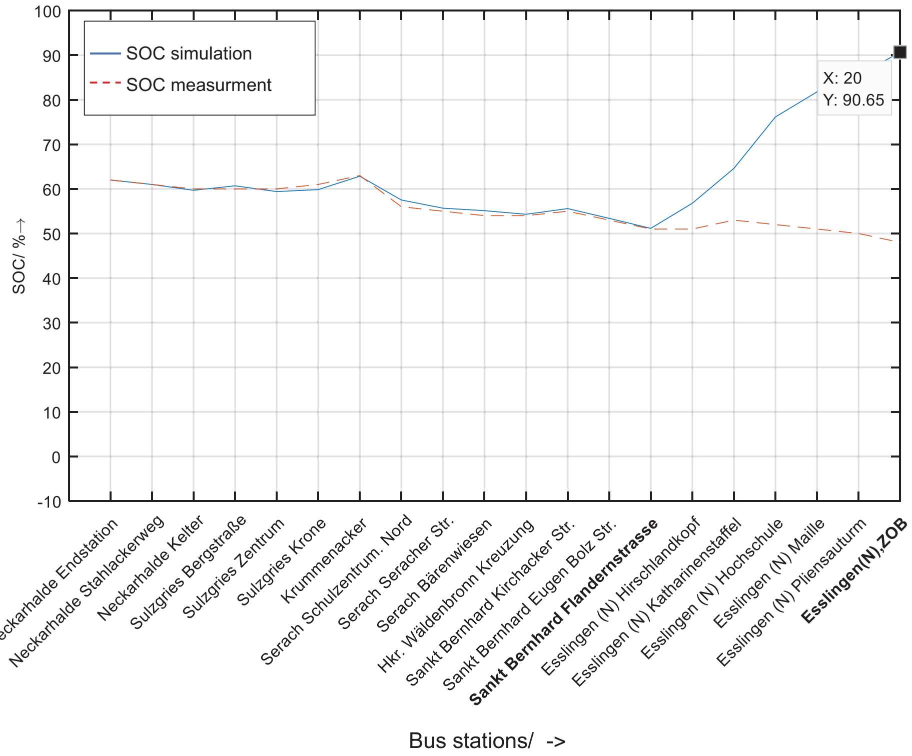

Figure 12.9: Pilot run: Neckarhalde to Esslingen main station.
(Source: Oberhauser 2018)

As it can be seen the simulation can be used to optimize the loading infrastructure regarding electric performance.

12.3.2 Methodology for Simulating the Energy- and Power Demand of a Bus

To move, accelerate and set a vehicle in motion, resistance must be overcome. The following picture (Figure 12.10) shows the forces acting in longitudional direction:

The overall resistance is divided into the following main parts:

Rolling resistance force $R_x = \sum R_{x,j} = mgcos(\theta) \sum w_j \ RRC_j$

$$w_j \ relative \ load \ on \ axle \ j$$

$$RRC_j \ rolling \ resistance \ coefficient \ axle \ j$$

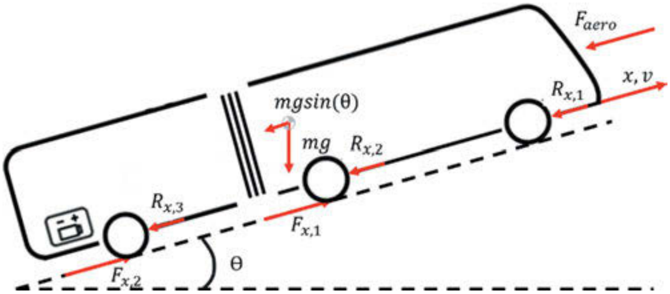

Figure 12.10: Bus forces.

Air resistance force	$F_{aero} = \frac{1}{2}\rho_{Air} C_d A_F v^2$
Gradient force	$F_{grad} = mgsin(\theta)$
Inertia force	$F_{inertia} = m\dot{v}$

The vehicle drivetrain has to generate longitudinal forces at all driven axles that overcomes the resistance:

$$\sum F_{x,j} = R_x + F_{aero} + F_{grad} + F_{inertia}$$

If the vehicle is in motion ($v > 0$) each force is related to a corresponding power:

$$\left(\sum F_{x,j}\right) \cdot v = R_x \cdot v + F_{aero} \cdot v + F_{grad} \cdot v + F_{inertia} \cdot v$$

$$P_{motion} = P_{roll} + P_{aero} + P_{grad} + P_{inertia}$$

$$W_{motion} = \int_0^T P_{roll} dt + \int_0^T P_{aero} dt + \int_0^T P_{grad} dt + \int_0^T P_{inertia} dt$$

The rolling resistance and air resistance forces are dissipative forces,that means the related power is always converted into thermal power and therefore wasted. Gradient and inertia forces are non-dissipative forces. The power generated by them increases the potential and kinetic energy of the vehicle. During downhill drive or deceleration, these powers have not to be generated by the traction motors via driveline but came out from decreasing potential and kinetic energy of the vehicle. Battery electric vehicles like the electro-hybrid bus can store a part of that energy via recuperation.

With constant system parameters and $\forall_j \; RRC_j \approx RRC$ the motion energy increase during measurement intervall $t\left[t_j, t_j + T\right]$ is equal to

$$\Delta W_{motion}\left(t_j+T\right)=mgRRC\int_{t_j}^{t_j+T} v(t)dt+\frac{1}{2}\rho_{Air}C_dA_F\int_{t_j}^{t_j+T} v^3(t)dt+mg\int_{t_j}^{t_j+T} \sin(\theta)dt$$
$$+m\int_{t_j}^{t_j+T} \dot{v}(t)v(t)dt$$

Integration over time finally leads to:

$$\Delta W_{motion}=mgRRC\cdot S+\frac{1}{2}\rho_{Air}C_dA_F\int_{t_j}^{t_j+T} v^3(t)dt+mg\left(h\left(t_j+T\right)-h\left(t_j\right)\right)$$
$$+\frac{1}{2}m\left(v^2\left(t_j+T\right)-v^2\left(t_j\right)\right)$$

with S distance travelled during $t\left[t_j,t_j+T\right]$
$h(t)$ height of the bus (e.q. above sea level) of bus at time t

This energy can be read as measurement value out of the electronic control units of the bus by connecting a diagnosis software tool with the internal bus communication system. The measurement results are used for a general calibration of the bus model.

As it is known from literature (Čulík 2021, Diab 2022) each electric driven vehicle needs in addition to the energy needed for motion also energy for heating in winter and cooling in summer (W_{HVAC}) and also for the auxiliaries (W_{aux}) (e.g. pneumatic brake, power steering, lights, electronic devices . . .). The amount of energy for heating a vehicle on a strong winter day with low ambient temperatures can be as much as high as the motion energy. The same occurs with electric air condition on hot summer days. Some city buses on the market have additional diesel combustion heaters but because of their negative environmental impact most have heat pumps.

The main difference between „normal“ battery busses and electrohybrid busses is that later cannot only be charged during stand-still (e.g. overnight) or by recuperation of the electric drives during breaking or downhill drive but can also be charged in motion when they drive under catenary.

The actual power flowing in or out of the battery when the bus is charged can be calculated:

$$P_{bat}=\eta_{charg}P_{charg}-\frac{1}{\eta_{Drive}}P_{motion}-P_{HVAC}-P_{aux}$$

The charging efficiency η_{charg}takes into account all losses between the catenary and battery and the drive efficiency η_{Drive} models thermal losses from battery, power electronic, electric drive, gears and tires. Both efficiencies are highly nonlinear functions of current, temperature, load, revolute speed and other physical quantities. Their values are taken from look-up tables during simulation.

There are technical limits both for maximum charging power and power flowing from the catenary line into the bus. For the actual generation of electrohybrid busses in Esslingen the limits are:

$$P_{charg,max} = 150 \ kW$$

$$P_{cat,max} = 350 \ kW$$

If during operation $P_{cat,max}$ is reached, the charging current will be reduced (priority for motion).

The following Sankey diagram (Figure 12.11) shows the energy flow of a electrohybrid bus after a drive mostly downhill on a part of line 111 without catenary. From that picture the losses of mechanical and electric/electronic parts can be read as well as all parts of motion energy.

During that drive 14,2 kWh electrical energy (set to 100%) have been flown out of the battery. Most part of that energy was converted to motion energy. Because of low speeds in downtown aereas contribution of aerodynamic forces to energy consumption (1,5%) could almost be neglected. Heating or cooling was not taken into account for that example.

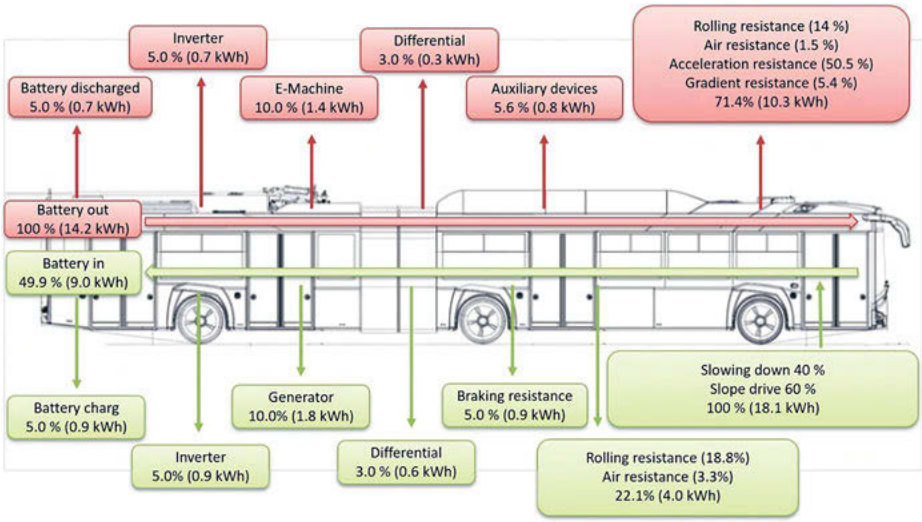

Figure 12.11: Sankey diagram of the traction battery Downhill journey using the example: Neckarhalde – Esslingen man station.

As approximation the state of charge of the traction battery can be calculated as:

$$SOC\ (t) = SOC(t=0) + \frac{100}{C_{bat}} \int_0^t P_{charg} dt$$

C_{bat} maximum (usable) chemical energy content of the battery.

Because of physical reasons the battery should never be fully discharged or fully charged. The battery of the first generation of electro-hybrid-busses has a total energy content $W_{bat,max} = 47\ kWh$. 80% of that energy can be used $W_{bat,min} = 4,7\ kWh\ and$ $W_{bat,max} = 42,3\ kWh$. For measurement and simulation the SOC value is refered to the usable range $C_{bat} = 37\ kWh$.

Real and simulated state of charge can be easily compared using data from a pilot run. The difference between both can be used for calibration e.g. of efficiency maps.

12.3.3 System Integration

The electrical energy supply is based on a very advanced technology. Many different interlocking components therefore contribute to successful implementation. Conversely, if an individual component fails, unfortunately the transmission path is also either partially disrupted or over disrupted over larger areas. It is therefore essential that the individual components are designed to fit precisely.

In the case of mobility by means of local public transport described here, the electrical connection is of particular importance. Whereas this connection is provided by a medium-level AC voltage (medium voltage of approx. 20,000 V) in this case, the trolley buses require a DC voltage of approx. 700 V. This means that both the voltage/current form and the voltage/current level must be converted. Physically, this transformation process is carried out in two steps. First, the voltage/current level is adjusted with the help of a transformer. Spatially, this is installed in its own small room, often also designed as a single-standing container, which is collectively referred to as a substation. Subsequently, the voltage/current type is adapted to the required specifications with the help of semiconductor components.

Special attention should be paid to the transformer. It is about the size of a small car and is therefore very cost-intensive. In the event of malfunction, this not only disrupts the supply of power to local public transport, but can also incur immense costs. It must therefore be optimally designed. This will be discussed in more detail below.

12.3.4 Criteria for Transformer Design, Thermal Limitation

The transformers used here are used in a flow converter mode. In this form of application, power limitations are predominantly based on thermal boundary conditions.

Physically, the limitation can be explained with the help of the Curie temperature. The transformer's base material abruptly loses its ferromagnetic properties starting from this material-dependent limit temperature. Curie temperatures range from 250 °C to 770 °C. Consequently, a sufficient safety margin must ensure that this limit temperature is not exceeded. Power losses during the transmission of electrical energy nevertheless heat up the entire structure. Although there are different types of losses with different dependencies, they have one thing in common: as the transmitted effective power increases, so do the losses. The time-dependent losses in the transformer as well as a temperature model are necessary in order to represent the time-dependent temperature. This makes it possible to run a time-limited overload in a transformer without it showing signs of failure (comparable to a cold saucepan that is placed on a cooker at full hob power. It is still cold after 5 seconds). These overloads can have different causes. Peak power is frequently attained when the trolley buses start up. This overload use case only lasts for a few seconds. At the same time, a transformer of this size requires an energy input of several minutes before it significantly changes temperature. Another potential overtemperature can occur during long-lasting power flows, such as those that occur when driving up the Zollberg. Apart from the kinetic energy, the trolley bus also has to expend a large amount of position energy in the process, which is why high power has to be transmitted by the transformer over a longer period of time. This type of load or, ultimately, the superposition of all load collectives of the trolley buses in the network is relevant for the design. A time grid of 15 minutes according to the transformer manufacturer's data sheet specifications is sufficient to make this observation. In order to do justice to this circumstance, the high-resolution, time series-based load flows are filtered for an evaluation using an equalised average value of 15 minutes.

12.3.5 Methodology for Determining the Maximum Power Requirement of a Substation: Monte Carlo Simulation

As already described above, you need to know the time-dependent power loss generated by the transformer in order to design a substation's transformer. The time-resolved transmitted power is relevant in order to determine this. It results in a percentage power loss (to be added). To determine the transferred transformer power, the power flow is analysed in reverse order. Based on a trolley bus, a time- and location-dependent power consumption is determined for this purpose. Then the feed losses to the trolley bus are determined and added to the bus power. This is done for each consumer (bus) in the distribution network. Using superposition, the total power attributed to the substation can then be determined. Nevertheless, a sequential approach is not possible due to cross-correlations of the distribution resistances. A parallel approach is necessary and it is described in detail below. According to chapter 12.3.1, the geographical movement profile of a trolley bus can be used to determine its locally absorbed electrical power. These movement profiles have been determined by means of digital GPS. Any route sections that do not exist have been generated by corresponding runs with a reference car. These movement profiles are broken down into smaller sections. The spatial limitation for this is given by bus stops. In the end, for a trolley bus route with X stops, you get X+1 partial routes, where always the first as well as the last one reflects the run to or from the yard of the municipal transport company. With the help of these partial routes, "any" real route sections can be put together within certain limits. This process is realised on the basis of a predefined timetable for the year 2020. Each route of each bus is reproduced broken down in time in the form of many partial routes. The time reference is the time of day based on which all sections must be adjusted by means of a timetable. If you look at the actual routing of the overhead lines, you can identify spatial areas that are each supplied by one transformer of a substation. Using this information in combination with the existence of simultaneous spatial consumers, the total time-dependent power consumed by consumers can be determined. A granularity of 15 seconds has been chosen in this case. The spatial allocation also makes it possible to determine the spatially resolved current density of the overhead lines (feeder lines) with the help of the specified DC voltage. Taking into account a real overhead contact wire, an electrical conductivity of >56m/Ωmm^2 can be determined with the help of the data sheet. This makes it possible, for a nominal cross-section of 120 mm^2, to determine an absolute power loss between the individual trolley buses. Other power losses such as contact resistances, etc., are added at a flat rate of one percent of the total power loss. Finally, all existing partial power in the recharge area of a transformer is added up in a time-resolved manner, which results in the total power to be transmitted by the respective transformer. Losses for rectifying the AC voltage are determined from the product of current and voltage of the 6 diodes (passive rectification). The diode voltage is taken from data sheets, whereas the current values are calculated back from the DC voltage. Finally, the transformer losses are determined as a flat rate of 5% of the total transmitted power (including losses for rectifying the AC voltage). Finally, a time-dependent power profile with associated power loss in the substations is determined.

Although the procedure described so far is based on an ideal route without external influences (apart from weather conditions), a large number of influencing variables nevertheless play a role in real runs. Variations in traffic flow density are significant here. In order to do justice to this circumstance, the routes are varied as follows:

- Each stop is given a boarding / disembarkation time of 3 minutes
- The boarding/ disembarkation time is modified at each stop with a normal distribution (variance 30 seconds)
- No bus can set off before it has pulled in
- No bus overtakes a bus in front of it
- From a delay of 20 minutes, the respective bus is taken out of service

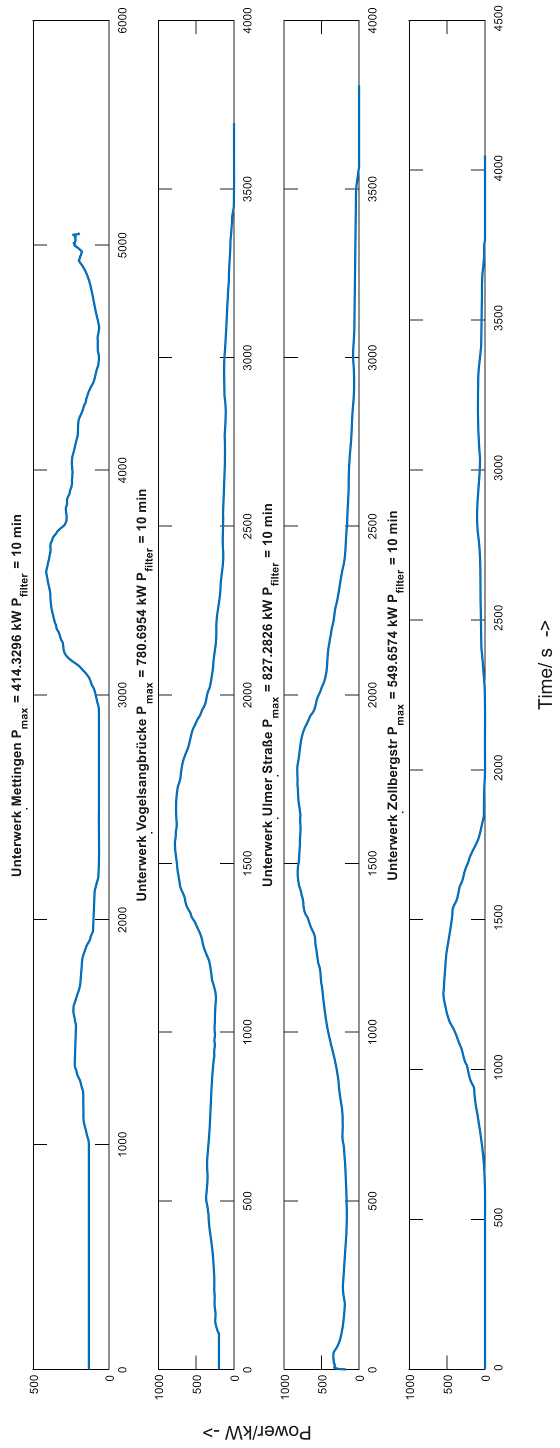

Figure 12.12: Maximum load profile of relevant substations.

These route modifications are varied using Monte Carlo simulation. Typically, between 2000 and 10,000 runs are simulated, depending on the requirements of the real time forecast. The maximum load profile of relevant substations averaged over 10 minutes for 2000 runs is shown as an example (Figure 12.12).

Classically, a robust design is required in the field of energy supply. It is also conceivable to accept savings in the area of infrastructure at the expense of calculable reduced availability. This circumstance is taken into account below. The transformer power averages are automatically divided into BIN classes: The aim of this approach is to divide the performance profiles into performance classes. The individual classes are defined with a maximum and minimum power, whereby these are directly adjacent to each other. If the transformer power exceeds a minimum power of the class, this increments a counter of this class. If the value falls below the limit again and is exceeded again at a later time, then the counter of this class is increased again by the value 1. Nevertheless, you must take into account that only one counter of a class is increased at a time, namely that of the highest performance class that occurred. The counters of the classes below this remain unaffected. Subsequently, all simulation runs are evaluated in terms of time. This means that if you choose the maximum power of transformer, you can select either a full installation (the maximum BIN class is lower than the maximum transmission power of the selected transformer) or alternatively a partial installation (the two limit values overlap). It is also possible to predict how often this case is most likely to occur over the simulation period shown.

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Felix Mayer, Florian Tischer, Johannes Walbrunn

13 Power System Supporting Control Strategy for Es_West_P2G2P – from Idea to Implementation

Summary: This paper deals with the smart grid of the climate district in Esslingen's Weststadt. First, the functionality of the electricity system and the effects of the electricity transition are discussed. Then, control objectives and the components in the smart grid are described. Finally, the implementation of the overarching energy management system and electricity market trading are discussed.

The expansion of volatile renewable energies is putting a strain on the electricity system. In addition to grid-based electricity surpluses, there are also market-based electricity surpluses. These can be absorbed and used with flexible loads. In the project presented here, this is mainly done by an electrolyser, which converts the electricity surpluses into hydrogen and thus makes them storable. In the event of a power shortage in the grid, the CHP unit can be switched on. This alternation of negative and positive electricity loads stabilises the electricity system. Since the electricity exchange prices also reflect the state of the grid, the power system-serving operation also creates an economic advantage.

The energy management system creates schedules for the components in the urban district based on forecasts of energy demand, renewable energy generation and the electricity exchange price. The schedules are integrated into the day-ahead market and booked in the balancing group. In addition, the smart grid reacts to short-term changes in intraday trading.

13.1 Introduction

By 2030, 80% of the German electricity system is to be supplied by renewable sources (BMWK 2022). This requires a considerable expansion of renewable energies. In Germany, photovoltaic and wind power plants have the greatest potential among renewable energies. However, their generation capacity depends on the weather and is therefore not adapted to the electricity demand. The addition of these fluctuating generation plants leads to new demands on the electricity system.

The electricity grid cannot serve as a storage system, which means that surplus electricity cannot be used at times. In the electricity system of the future, innovative concepts are needed that can adapt to the fluctuating generation capacities. One possibility is so-

Felix Mayer, Green Hydrogen Esslingen GmbH
Florian Tischer, Polarstern GmbH
Johannes Walbrunn, Consolinno Energy GmbH

https://doi.org/10.1515/9783110777567-013

called smart grids, which can absorb power surpluses at the urban district level and temporarily supply themselves in times of low wind and sun or even actively support the power system. Such flexible smart grids can also be used to link different sectors.

As an example, the demonstration project in the new Weststadt Esslingen will be discussed. There, a smart grid is being created that reacts to the demands of the electricity system and contributes to the economic expansion of renewable energies.

13.1.1 Challenges in the Course of the Electricity Transition – Grid Expansion and Flexible Consumers

Renewable energies have been massively expanded in the last 20 years (Federal Environment Agency 2021). Due to the faltering grid expansion and the lack of flexible loads that can be connected, electricity surpluses arise that cannot be used. As a result, wind and PV plants are regulated by the feed-in management and the renewable electricity is not used. In such cases, the plant operators are financially compensated for the lost revenue. The costs incurred by such feed-in management in 2019 amounted to around 710 million euros. In 2020, the figure was around 760 million euros (Bundesnetzagentur 2022).

These curtailments can arise for two reasons. Firstly, due to grid-based electricity surpluses. In this case, the capacity of the electricity grid is not sufficient to transport the electricity from the sources to the consumers. This can be avoided by a targeted expansion of the electricity grids.

The second reason for curtailments is market-based electricity surpluses. If the electricity grid is perfectly developed, the market is decisive. Only when supply and demand coincide is the electricity system in balance.

Both are needed to prevent the curtailment of renewable energies: A well-developed electricity grid and stable electricity trading. The electricity grid is being continuously expanded. This paper is about stabilising the electricity market with flexibly deployable electricity consumers and generators. This is becoming increasingly relevant due to the fluctuation of renewable energies and their increasing share.

13.1.2 How Electricity Trading Works

In electricity trading, a fundamental distinction is made between two market forms: Long-term trading on the futures market and short-term trading on the spot market. The latter is in turn divided into the market for electricity deliveries for the following day (day-ahead) and the current day (intraday). On the spot market, market participants have the opportunity to physically balance out surpluses or shortfalls due to short-term changes. The futures market, on the other hand, is used for long-term price hedging.

On the day-ahead market, electricity deliveries are auctioned for each individual hour of the following delivery day. Trading is based on current generation and consumption forecasts. Bids can be submitted until 12 noon. The supply and demand curve finally results in the market price for the respective hour (Graeber 2014). Since supply and demand vary constantly, different electricity prices result for the individual hours.

To minimise electricity costs, the generation plants with the lowest marginal costs are awarded first (merit order). The merit order therefore maps the order in which the power plants are used, sorted in ascending order of price. In the merit order principle, the electricity price is determined by the most expensive power plant still required to cover the respective electricity demand in the hour in question. The electricity price therefore usually corresponds to the marginal costs of the most expensive power plant and is therefore referred to as the market clearing price (Graeber 2014). This market clearing price is then paid by all market participants for the electricity deliveries in the respective hour.

The intraday market serves to balance out intraday forecast deviations. This is because the fluctuating feed-in from renewable energies makes the long-term prediction of feed-in forecasts increasingly difficult. Trading of hourly and 15-minute blocks is therefore possible here at very short notice up to 5 minutes before the start of delivery.

An essential difference to the day-ahead market is the price formation mechanism on the intraday market. In contrast to the market clearing price, in continuous trading the prices are determined in the pay-as-bid procedure. This means that the exact price of the bid submitted is collected. This results in different prices for the same delivery product.

13.1.3 Impact of Renewable Energies on Electricity Trading

The electricity production costs from renewable energies are lower than those of conventional power plants. This is due to the fact that they are subsidised under the „Erneuerbare-Energie-Gesetz“ (short EEG, in english Renewable Energy Sources Act), no use of fuels is necessary and they do not emit CO_2. The feed-in of electricity production from photovoltaics, wind energy, biomass and hydropower also takes place with priority according to the EEG. On days with high feed-in from renewable energies, the conventional power plants with higher electricity production costs are partly no longer needed to cover the current electricity demand. Power plants with higher production costs are thus pushed out of the merit order and replaced by more cost-effective generation plants from renewable energies (Graeber 2014). This market mechanism is also referred to as the merit order effect. A high feed-in from renewable energies thus leads to lower spot market prices.

Depending on the market phase, the electricity exchange price reflects short-term changes in supply and demand as well as the share of renewable energies in the electricity mix. The price applies to certain blocks – hours or even quarter hours – and can behave very erratically. If electricity is purchased when exchange prices are low and electricity is fed into the grid when prices are high, supply and demand are brought closer together. Although market equilibrium is not synonymous with a stable grid condition, it is a prerequisite for functioning electricity trading. Energy-efficient integration of fluctuating renewable energies into the electricity system therefore requires not only functioning electricity trading but also intelligent interconnection of grids, generation, storage and loads in smart grids in order to optimally coordinate energy production and consumption and, if necessary, to physically balance power fluctuations and bottlenecks in the grid. Flexible loads, which are used specifically when spot market prices are low and thus usually when there is a high feed-in from renewable energies, can thus stabilise the electricity system in addition to the market.

13.2 Smart Grid – Definition and Boundary Conditions

A smart grid is a network of storage facilities as well as controllable and non-controllable loads and generators. Different sectors can be coupled with each other, thereby exploiting synergy effects. The holistic view of an energy system enables optimised interaction, for example, between electricity and heat supply and charging stations for e-mobility. The following section uses the example of the "Climate district Esslingen" to describe its control objectives, the components considered for this purpose and the prerequisites for successful implementation.

13.2.1 Control Objectives of the Climate District

The main objective in the urban district is the security of supply for the users, especially for heat, as the electricity can be drawn from the grid. The outcome goals of the smart grid control are to avoid CO_2 emissions as much as possible and at the same time to enable economic operation. The main procedural goals for this are to maximise the use of self-generated electricity and to interact flexibly and efficiently with the electricity system. The latter is made up of the following considerations:

- Maximise the use of self-generated electricity: The use of electricity generated in the urban district is often cheaper than purchasing it from the electricity grid. A high degree of own use passively relieves the electricity system by placing less of a burden on it.
- Day-ahead trading: The optimized use of flexible generators and consumers based on the day-ahead price forecast makes economic sense, takes into account generation from renewable energies and thus actively contributes to a stable electricity market.
- Intraday trading: Balances out short-term changes between supply and demand. If electricity is purchased when the exchange electricity price is favourable (buyer's market) and electricity is fed in when the exchange electricity price is high (seller's

market), supply and demand are brought closer together and a market equilibrium is created. This enables economic advantages for the flexibility of the smart grid. In addition, the electricity system is actively supported at short notice.

13.2.2 Components of the Climate District

For the Smart Grid in the Esslingen climate district, the first step is to focus on the components with the greatest potential. These are power sources or sinks that can be flexibly controlled. They require a fast response time and high availability. The effect of the displaceable energy quantity depends on their performance and capacity. The most important components are briefly described below. Further information can be found in chapter 10.4 Insights – Climate urban district Neue Weststadt.

The **electrolyser** is a flexibly switchable load with up to 1 MW of electrical input power. Start-up from standby takes only a few seconds. The hydrogen can be stored in the natural gas grid or can be converted back into electricity in the CHP if required – further H_2 utilisation paths are under development. The waste heat is used directly in the urban district or stored temporarily. Excess waste heat that cannot be used is dissipated via a recooler. This allows the electrolysis plant to be used very flexibly. There are almost no dependencies that limit operation. For reasons of efficiency, simultaneous operation of the electrolyser and the CHP unit is not planned.[1]

The **CHP** is an electricity and heat generator. Its availability as a flexibly connectable electricity generator depends on the heat buffer storage. The CHP unit should only be operated if the heat can be used or stored. Purely heat-led operation is not future-oriented and is neglected for the smart grid. The electricity demand should be covered at the times of greatest demand.

Photovoltaics has no potential for load shifting; its output depends on solar irradiation. Nevertheless, it can generate almost climate-neutral electricity, which needs to be integrated into the smart grid.

A **wind turbine** on the Swabian Alb is another renewable energy source. It is connected to the same electrical balancing group as the electrolyser. The output is dependent on the wind and cannot be regulated, but is also taken into account in the Smart Grid.

The **electricity grid** is taken into account as the final source and sink of electricity. Purchase and feed-in from the smart grid should relieve the electricity system as much as possible.

1 Generating gas from electricity with the electrolyser while simultaneously using gas to generate electricity with the CHP unit makes no sense; a heating rod would be more efficient and cheaper to generate heat.

13.2.3 The Overarching Energy Management System

In order for the components in the smart grid to be intelligently networked and the control objectives to be optimised while taking external dependencies into account, a higher-level energy management system (EMS) is required. The development of such a cross-quarter EMS requires corresponding sensors, actuators and software solutions. In order to manage the interaction of processes and procedures, the signals and measured variables of internal sensors and external signals are recorded centrally.

(System integration enables communication between the individual sensors and actuators and the EMS. The area of active energy management deals with the programming of the control loops. With these two areas, automated building control is made possible. To this end, the EMS also complements the energy market-oriented component the operation and place the smart grid on the market. A contractor is needed for the coupling with the electricity market. Other areas such as balancing group balancing or the provision of control power can also be taken into account for market operations (Nagl 2020).

The EMS takes into account the control objectives and uses them to optimise the operating times of the components in the urban district. For example, the CHP unit can only be operated if the heat can also be taken in the urban district or temporarily stored. In addition, the demand of the higher-level electricity system should also be taken into account. These requirements result in a time window in which the CHP unit can run.

13.3 Implementation of the Control Strategy

This chapter deals with the implementation of the control objectives explained above. Using the example of the climate district, the control pyramid applied there is described. Subsequently, the functioning of the optimised schedule generation and its transmission to the electricity market contractor will be explained.

13.3.1 Energy Management and Control Levels

The control concept is mapped in a control pyramid with three levels. The control levels guarantee security of supply and also enable to bring the flexibility of the smart grid to the market. Control levels are shown graphically in Figure 13.1.

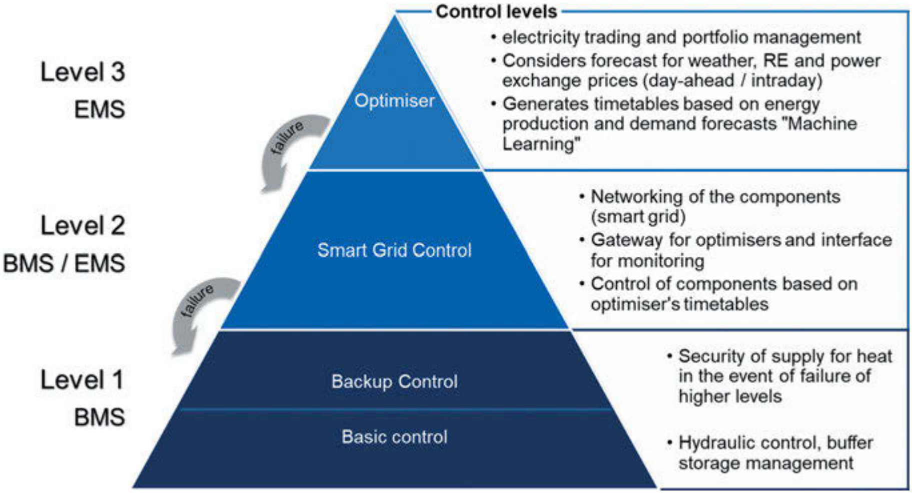


Figure 13.1: Control pyramid.

Basic and Backup Control (Level 1)

This control level is permanently in operation and runs via the building management system (BMS). The basic control is mainly responsible for the hydraulics of the heat supply by controlling valves and pumps based on temperatures and pressures in order to bring the heat to the users.

The backup control guarantees the security of supply of heat in the urban district by maintaining a minimum temperature in the heat storage tank through the gas boiler. The security of supply in the electricity sector is guaranteed by the public electricity grid.

The higher control levels should ensure that the minimum temperature in the storage tank is permanently maintained and thus the backup system does not have to intervene during control operation. In case of failure, the backup intervenes.

Smart Grid Control (Level 2)

The second control level connects the components in the urban district to form a controllable unit. Here, the components are connected via the respective communication protocols, which serves as a gateway for control by a higher level. This control takes into account the urban district internal optimisation of electricity and heat generation. In addition, timetables from the ptimiser can be stored temporarily. Via this level, the EMS can collect all relevant data, which is used for the forecasts and also for monitoring. If this control fails, the backup control takes effect.

Optimiser (Level 3)

The third level is to optimise the whole operation by connecting internal requirements with these from the external energy system and market the flexibilities of the smart grid. This is done with the help of “machine learning” and by taking many influencing variables into account. Past demand in the urban district is recorded and compared with other data such as weather, day of the week, holiday, time of day, season, and much more. From this, an algorithm “learns” the correlations, weights them and can thus automatically create forecasts for the future. By combining these forecasts with, for example, electricity market prices, an optimised schedule can be created for the smart grid. If the forecast deviates too far from reality and the schedule cannot be adhered to as a result, the optimisation level switches off and the smart grid regulation takes effect.

Parallel to these control levels, there is a safety PLC that monitors the H_2-production and H_2-storage rooms at all times. In the event of malfunctions, this safety system intervenes fully automatically based on a predefined safety matrix.

In addition, the electricity grid operator can shut down the electrolysis plant via a grid module if the additional load endangers regional grid stability.

13.3.2 Optimiser – How the Timetable Creation Works

In addition to the various optimisation goals, there are certain specifications and framework conditions that must be taken into account by the EMS. These can be, for example, that the electrolysis is never to be operated at the same time as the CHP unit. Furthermore, it must be ensured that as much waste heat from the electrolysis as possible can be used in the heat network.

A price forecast for the day-ahead market is used for the optimised operation of the electrolyser. This means that hydrogen production is scheduled for the times when the feed-in from renewable energies is as high as possible (see merit order effect). In addition to this energy market-oriented management of the electrolyser, a large part of the electricity required is to be obtained directly from renewable generation plants in the smart grid. In addition to photovoltaics in the urban district, a supply contract was also concluded with a wind power turbine for this purpose. The forecast of this wind turbine is thus a further input for the operation of the electrolyser. Consequently, the optimizer decides according to the power production of PV and wind as well as the power demand in the district, which component to be operated: the electrolyzer for production of hydrogen or the combined heat and power plant.

The different components in the smart grid, as well as the different control objectives, allow a large potential for optimisation by the EMS. Since the electricity quantities have to be marketed in advance, no event-based control is used for the implementation, but a forecast-based optimisation. This consists of three main components: The forecast algorithm, the digital twin of the energy system with its boundary conditions, and the cost function on the various energy flows.

Sensors and Forecasting

Machine learning algorithms are used for the forecasting algorithm, which predict the electricity and heat demand as well as the PV generation in the urban district. Internal measurement data as well as additional external data, such as weather data or wind power forecasts, but also data such as time of day/year are used to create the forecasts. For the forecast of the heat demand, for example, the meter of the total amount of heat purchased is used and not every single meter in every household. The measured values are collected and then converted into a forecast using machine learning algorithms. Depending on the requirement, the forecast horizon is three to five days into the future. These forecasts are passed on to the mathematical model of the digital twin for timetable optimisation.

Optimisation

Due to the complexity as well as the different optimisation goals, the "Mixed Integer Linear Programming" method is used for the modelling. This includes all relevant components of the energy system as well as their relationships to each other in the form of energy flows, also between different sectors. A solver solves the system of equations using a previously defined objective or cost function. This consists of minimising or maximising cost terms, which are parameterised to the energy flows of the digital twin. In the digital twin, all relevant costs – for example gas purchases, heat revenues, exchange electricity prices – are assigned to the corresponding connections and the target function is then minimised using the solver. The solver determines the schedule that both complies with all boundary conditions and minimises the operating costs or generates maximum revenues.

This procedure is shown schematically in Figure 13.2.

The sequence of forecasting and timetable optimisation by the digital twin is integrated into an automated process. Based on the demand from the urban district or the electricity market, this process is triggered at different times of the day. In this way, up-to-date schedules are always generated for the controllable generators and consumers in the smart grid. After a subsequent check, the schedule is transferred to the Smart Grid control system. At the same time, the schedule is reported to the corresponding marketing service providers in order to trade the electricity quantities in the day-ahead or intraday market. More in the following chapter.

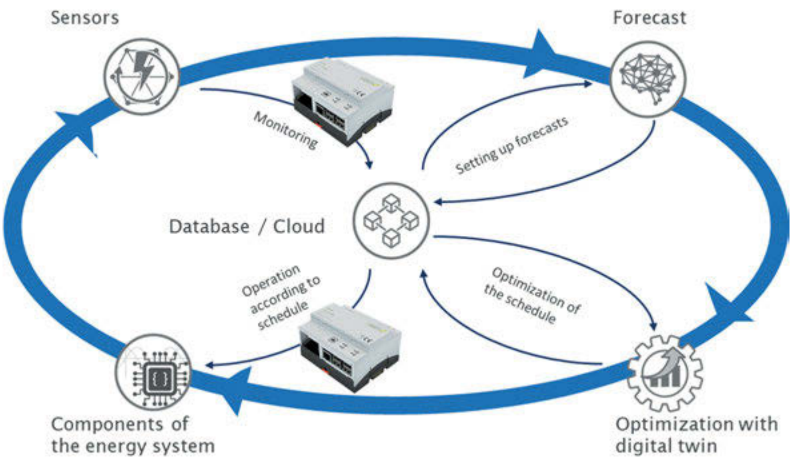


Figure 13.2: Graphical representation of timetable creation.

13.3.3 Data Exchange for Creating the Optimised Timetables and Trade them on the Electricity Market

In order to ensure a smooth process flow, electricity market data and generation forecasts are continuously exchanged between the EMS and the service providers responsible for energy trading. This concerns both the electrolyser's energy purchases and the energy sales from CHPs, PVs and wind turbine.

The day-ahead schedule is always prepared in the morning for the following day. The necessary spot price forecast for the day-ahead market is received by e-mail at 7:00 am. The current wind power forecast is sent by e-mail at 09:15 am. After receiving the forecasts, an optimisation is triggered. Based on the price signal, the wind power forecast and the self-generated forecasts for the energy requirements in the urban district, this generates the minimum-cost deployment schedule for the electrolyser and CHP. The respective schedules for the following day are reported to the schedule management of the energy supply company or the direct marketer by 9:45 am, at the latest. The reports are also made for several days into the future in order to have a backup in case of system disruptions. After the schedule has been reported, the direct marketer enters it into his system and then markets his portfolio on the day-ahead market. To do this, he submits a bid on the day-ahead market by 12:00 noon. The costs on the energy flows as well as the provided flexibility in the energy system according to the forecasted supply and demand is updated by every cycle of the optimization. Therefore, a dynamic and automated workflow is established.

In addition to the energy supply company, the schedules are also sent to the smart grid control level in the urban district and temporarily stored there in order to ensure schedule reliability even if the connection to the cloud is lost. This is done by the on-site hardware, the Consolinno Leaflet.

Schedule fidelity is very important, as deviations between the reported and actual schedules jeopardise the balance in the power system and lead to balancing energy costs. Since the forecast for wind power can change within a day and since forecast deviations can occur in the area of on-site demand, the intraday market is used in addition to the day-ahead market to be able to react to such events. For this purpose, an ongoing re-optimisation of the schedule is necessary after receiving the intraday wind power forecast deviations. The current intraday wind power forecast arrives on a rolling basis every five minutes for the next six hours. The schedule adjustments are reported to the energy supply company accordingly. Even if there are major deviations between the energy demand forecast and the real situation, such a subsequent optimisation takes place.

An overview of the communication channels and coordination services is shown graphically in Figure 13.3

13.4 Outlook

Smart grids are well suited to support the electricity system of the future and can thereby couple the electricity sector with other sectors. The energy market-oriented smart grid benefits from highly fluctuating electricity prices and the fluctuating electricity system of the future in turn benefits from the flexibility of the smart grid.

For operation, green electricity and green gas are used on balance to enable the climate-neutral supply of the urban district even now. The operation of the components also supports the electricity system so that renewable energies can be expanded and better used. By expanding renewable energies, the concept could thus be climate-neutral in a few years, even without green electricity certificates.

Placing this flexibility on the electricity market opens up a new market that has not yet been given much attention in the area of building supply. This offers the districts great – also economic – potential to contribute to the electricity and energy transition.

The goal should be to promote the flexible purchase of electricity by adapting the regulations of energy transition and management in order to better integrate the fluctuating power from renewable sources and thus improve the CO_2 emissions of the German electricity mix.

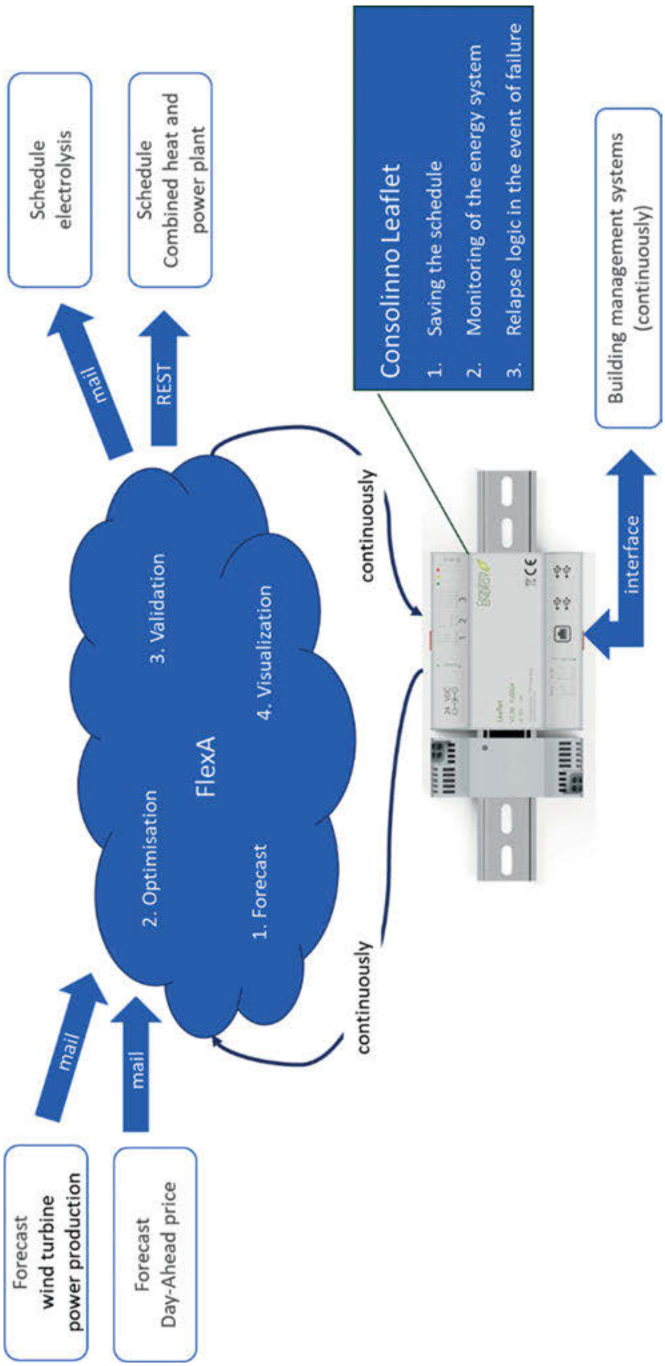
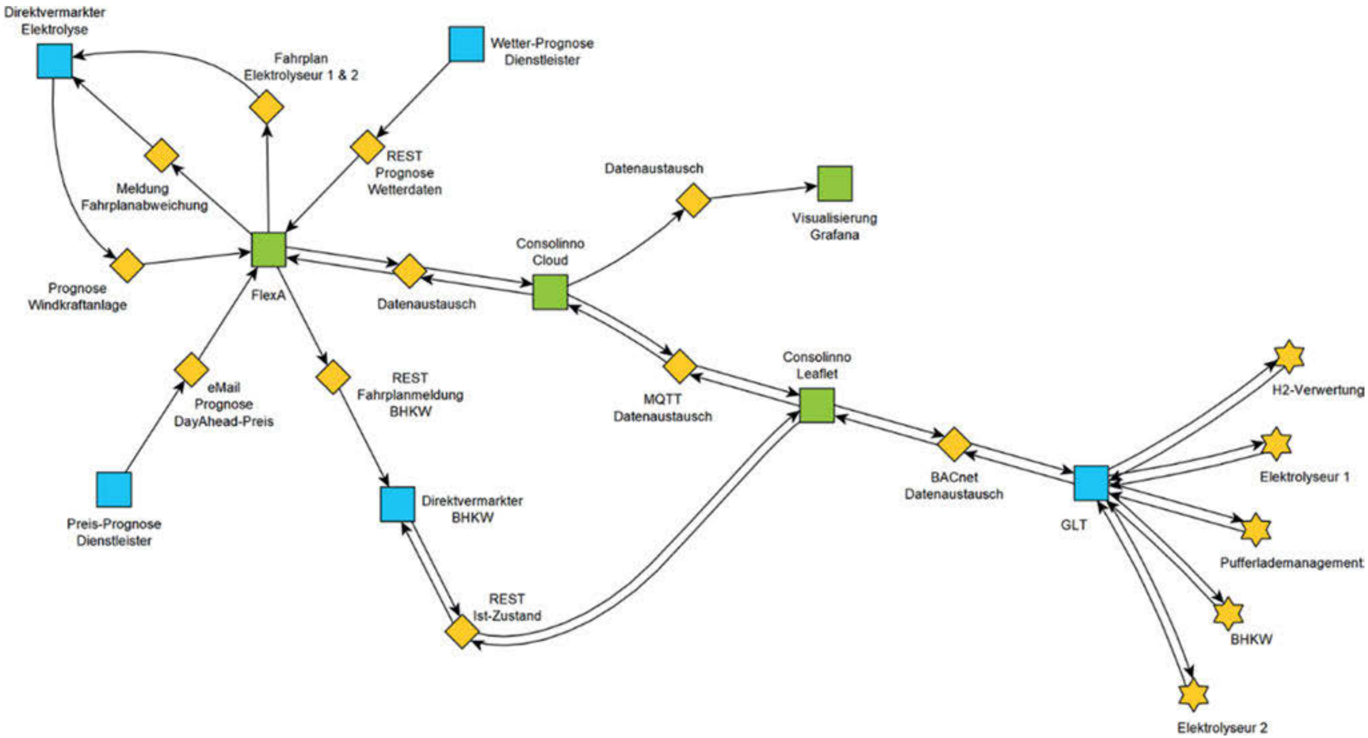


Figure 13.3: Control overview with the higher-level interfaces (2021).

Units

MW Megawatt



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Felix Bader, Dominikus Vogl, Janika Gabriel, Eva Schulze

14 Social Research to Enable Human-Oriented Energy Transition. Results from a Climate District

Summary: Social research on energy transition projects provides valuable feedback at human-technology intersection, especially acceptance of new technologies. To collect user acceptance, attitudes and behaviour, the social research group in Esslingen's climate district "Neue Weststadt" used standardised surveys and qualitative interviews. Results show that residents are successful young professionals, that do not meet the stereotype of intrinsically motivated "ecowarriors." While they are not fully aware of the climate district's innovative concept, residents live well, and express no concerns about the applied technological innovations, including local production of hydrogen and storage in residential area. A transfer of the positive Esslingen experiences to other target groups, such as older persons, is not self-evident but requires further research. We call for an improvement of communication with and participation of residents. This would enable spill-overs of climate progressiveness to other areas of action.

14.1 Introduction

Nationwide surveys show that the population of Germany supports a systematic and rapid execution of the energy transition (Rubik 2019) and Belz/Follmer/Hölscher et al. (2022) claim that "the issue of environmental protection and climate action has not lost any of its importance." Housing and energy production are important factors to contribute to climate protection. Yet, energy-efficient housing is not always supported by users and renewable energies' production sometimes meets notable resistance.

Social research in energy transition projects focuses on attitudes and behaviour, and evaluates user acceptance of technologies as well as residents' wishes and expectations related to local infrastructure and climate-friendly energy supply. Hence, social research verifies the actual functionality and suitability of a climate district for everyday life. Social research aims to optimise and support technical operation on the one hand and to ease users' active participation on the other. Insights from a climate district with high acceptance can be considered a successful role model and best practise example for comparable future projects.

In the city of Esslingen's climate district "Neue Weststadt", technical approaches of energy-efficient housing, production of solar energy, and energy storage using hydrogen are

Felix Bader, **Dominikus Vogl**, **Janika Gabriel**, **Eva Schulze**, BIS Berlin Institute for Social Research

https://doi.org/10.1515/9783110777567-014

tested in combination. Complementarily, residents are encouraged to save energy and use climate-friendly means of transportation. Residents' user acceptance, attitudes, and behaviour are monitored by a social research group of the Berlin Institute for Social Research (BIS). Thus, the city's "Neue Weststadt" can be classified as a transdisciplinary living lab (Borner/Kraft 2018) applying and evaluating system integration (BMWK 2016). Experts rate energy storage as one of the most important topics for energy-efficient housing – among building technology, production of renewable energy, and heat insulation (Schulze/Gabriel/Dietel et al. 2017), which are also integrated in the Esslingen project. The same experts also rank energy storage as the technology with the highest need for research and development.

Society's challenge of the near future will be to adapt and apply climate-protection measures for the broad majority of the population. Earlier projects on energy-efficient housing were often inhabited by volunteers self-selecting into climate-friendly houses for ideological reasons. These persons' judgments might be biased. We should, thus, evaluate energy-efficient housing and other climate-protection technologies in their everyday suitability and acceptance for varying target groups. Esslingen's climate district is an example for such an application.

Earlier projects on energy-efficient housing report limited user acceptance due to new but less reliable technologies (14.2). These problems seem to have been largely overcome. To evaluate this, the social research group in Esslingen used standardised surveys and qualitative interviews (14.3). The results (14.4) reveal that the residents of the "Neue Weststadt" climate district are young professionals and no ecowarriors (14.4.1). They are not fully aware of the district's innovative concept (14.4.2), and most of the aspects they like or dislike about their flats are not related to the concept of climate protection (14.4.3). Overall, one can live well in the climate district. Residents also have no concerns about the district's technological innovations (14.4.4). Concluding (14.5), we point out that a transfer of the positive Esslingen experiences to other target groups, such as older cohorts or less educated people, is not self-evident but requires further research. We call for an improvement of communication and participation including residents. This would enable spill-overs of climate progressiveness to other areas of action.

14.2 Related Social Research on Energy Transition in the Housing Sector

Technical solutions implemented in earlier energy-efficient housing projects were rather often criticised by their residents. To find better user acceptance residents' active involvement in the decision-making processes became necessary. In the following, we give a short overview of experiences from previous projects on energy-efficient housing including user acceptance. For reasons of comparability in terms of applied technology, economic development, and culture, this review focuses on projects in Germany and Austria completed in the last two decades.

At the turn of the millennium, residents in blocks of flats designed in the passive house standard (Ornetzeder/Rohracher 2001) complained especially about limited possibility to regulate room temperature, dry air in winter, and annoying sounds of the ventilating system. Other objections were not (directly) related to energy engineering, like conflicts between neighbours, sizes or layouts of the flats, or costs for district heating (Stieldorf/Juri/Haider et al. 2001). Users involved in choosing technologies more easily classified malfunctions of the energy technology as irrelevant. Furthermore, a relationship between satisfaction with energy-efficient housing and the degree of responsibility for decision-making in the construction process was found (Keul 2001). Single-family houses, which in general have higher user involvement achieved higher ratings for climate friendly energy systems (Rohracher/Ornetzeder 2008).

High levels of user satisfaction were observed in more recently build or refurbished energy-efficient single-family houses (e.g. Oesterreich/Zirk/Dietel et al. 2015). That may be a side effect of more developed and established technology. In the study of Oesterreich/Zirk/Dietel et al. (2015), air quality and temperature were rated as comfortable, but users' introduction to the new housing technology was assessed as insufficient. In Germany, environmental concern is high with strong support for technological innovations regarding the energy sector (Belz/Follmer/Hölscher et al. 2022). At the same time research indicates that high environmental concern doesn't necessarily result in more environmentally friendly behaviour (Diekmann/Preissendörfer 1998).

Recent projects in energy-efficient blocks of flats achieved high satisfaction ratings. For the tenants, energy efficiency ranked among the top three reasons for moving in, and by living in an energy-efficient house they were inspired to become even more aware of their energy consumption (Schulze/Dietel/Engler 2018). Consequentially, optimistic ratings were to be expected. Residents rated room temperature fairly well, but evaluated air quality more negatively. The ventilation system produced annoying sounds in this project while the air still was not fresh and humid enough. Hence, residents feel the need to open windows even in wintertime. Lower energy consumption and heating costs were attained, but technology was still failure-prone.

Similar results were found for the private spaces in a modular plus-energy student dormitory in the city of Frankfurt (Joppien 2019). Temperature was comfortable, but windows had to be opened to get enough fresh air. Residents did not fully understand the usage and adaption of the housing technology and interpreted it as malfunctioning.

Current studies show high acceptance of energy-efficient restoration measures, provided that the reduction of energy costs compensates for the increase in rents (Haug/Vetter/Weber 2020).

Over the last decades, technology of energy-efficient housing seems to have matured, but reliability and user acceptance are still not fully achieved. Participants of many previous studies were volunteers who decided to live in an energy efficient housing project for ideological reasons. Thus, their ratings of technology acceptance can hardly be transferred to other groups. To the best of our knowledge, no previous study covered acceptance of hydrogen production and storage in a residential neighbourhood.

14.3 Methods

The data for the social science part of the Esslingen climate quarter were collected using a standardised online survey accompanied by qualitative interviews with selected residents.

All residents of the accomplished blocks of flats called Béla and Citadis in "Neue Weststadt" were invited to participate in the anonymous survey by postings in the entrances of the buildings and flyers in their letter boxes in October 2020. Residents had to register with their e-mail address in order to participate. Apart from discouraging non-residents from participating and impeding accidental or conscious duplicate participation, it allows to match answers between the four questionnaires on different topics each household was asked to complete. The e-mail addresses were encrypted, so the data do not contain any identifiers.

Two e-mails were sent by the project developer and property manager RVI to remind the residents to participate. Both reminders led to noticeable increases in the answering rates. Additionally, a lottery – first prize: voucher for a carbon neutral five-course dinner in a local restaurant – was implemented to increase interest in participation.

Four topics were covered in separate questionnaires:

– Living in a climate district (81 respondents)
– Social life/neighbourhood in the climate district (62 respondents)
– Mobility behaviour of the residents (65 respondents)
– Energy consumption of the residents (55 respondents)

Residents were asked to fill in all questionnaires but could freely choose the order of completion. 84 households answered at least one questionnaire. With about 260 households contacted, the response rate of 32% is quite high for an online survey.

14.4 Results

In the following, we present results from the social research in the climate district "Neue Weststadt". We portray the people living in the climate district, how well they were informed about their district, their main complaints about their flats and their neighbourhood, as well as their receptiveness towards new technology.

14.4.1 Residents are Young Professionals, No Ecowarriors

Residents of Esslingen's climate district "Neue Weststadt" are a quite homogenous group: young adults without children, highly educated, and professionally successful.

97% percent are tenants, only 3% of the residents are owners. The rent accounts for 30% or less of their income in about half the cases (48%), and accounts for up to 40% in another 33% of the cases. Given that the rents in these newly constructed high standard buildings close to the centre of Esslingen are rather high, the participating residents appear quite wealthy. 93% graduated from a university or from a university of applied sciences. 92% work full-time. 34% are less than 30 years old, another 50% between 30 and 39 years. 39% live alone, 53% in a two-person household. 88% have no children. Thus, it is obvious that the residents are not a representative sample of the German population but rather successful, highly educated, young adults who want to and can afford living in a modern flat in the city centre.

As Figure 14.1 shows, residents of the Esslingen climate district express strong pro-environmental attitudes and claim to be personally willing to contribute to save energy. These results are not surprising, given their age and level of education.[1] As far as specific measures of environmental behaviour could be collected, the residents in contrast to their proclaimed values are not overly pro-environmental in their behaviour. For example, 78% owned at least one car – quite a high value for young residents of an inner city. 94% of their cars had conventional combustion engines (petrol or diesel). The remaining ones were hybrid cars, but only one plug-in hybrid. In the field of energy consumption, residents' usage of electric devices, heating, and hot water also indicate average lifestyles. Only 4% partly align the timing of their energy consumption with the energy production period of the house (sunshine). Altogether, results show, that residents are no ecowarriors.

14.4.2 Limited Knowledge of the Innovative Concept

The fact that Esslingen residents did not select themselves into the climate district because of their motivation to actively contribute to environmental protection originates in the circumstance that at this time many were not actively informed about the innovative concept of the district.

People chose to live in the "Neue Weststadt" based on their individual needs. As reasons for their choice, most people mention the proximity to the main station, the city centre, or their workplace. Day light in the flats and modern design are often highlighted positively. Aspects of energy efficiency or environmental friendliness were not in residents' forefront of awareness. Almost all of them did not choose to live there because of its climate-friendliness, but rather wanted to live in a newly built, modern, urban residence.

1 For similar results, see the current Environmental Awareness Study 2020 by the German Federal Ministry for the Environment and Consumer Protection (Belz/ Follmer/Hölscher et al. 2022).

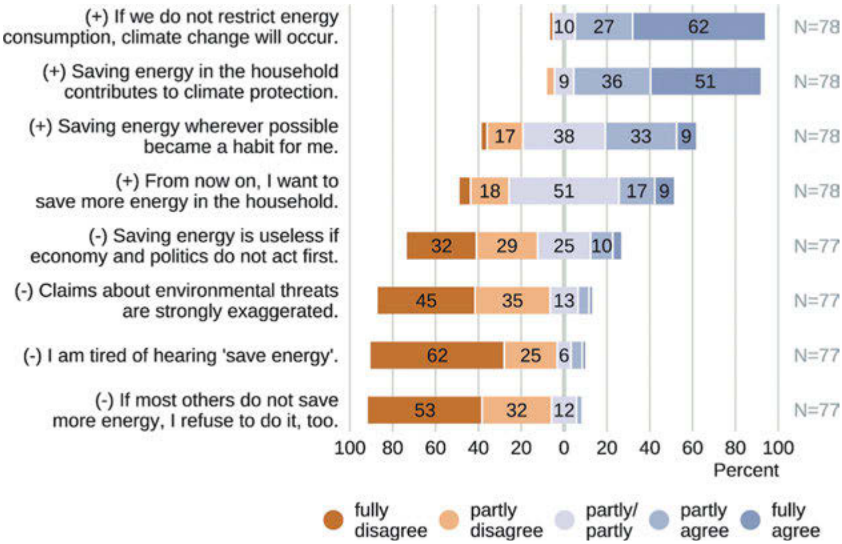

Figure 14.1: High environmental attitudes of the climate district's residents.

In fact, the residents were not particularly well informed about the special energy supply concept of the district before moving in. Even in the survey data collected one to two years after moving in, only 42% knew that hydrogen is being produced from self-produced green energy and stored below the buildings (see Figure 14.2). 87% of the respondents report to have known that the "Neue Weststadt" is a climate district, but only 66% informed themselves further what this entails. This information deficit was also confirmed in the qualitative interviews.[2] The lack of information relates to the fact that the property manager RVI did not communicate detailed information about the energy concept. At the time when the flats in block Béla (the first of the blocks to be completed) were first rented out, it was still unclear if the funding for the research project would come through and how the energy concept would be realised. Additionally, Covid-related restrictions prevented information events.

Among residents, the district's climate concept is not an important topic in conversations. 11% of the residents state that they are approached on the climate concept by outsiders. Only 2% agree that the climate concept is a topic to start a conversation with other neighbours.

The upside of residents' knowledge gap regarding the climate concept is that it allows to check whether residents take notice of any shortcomings regarding the district's technological innovativeness. Problems related to energy-efficient housing observed in previous research projects (mentioned in Chapter 14.2), like difficulties with temperature regulation, dry room air, or noises of the ventilation system, were per-

2 Keul (2001) mentions a similar information deficit.

ceived rarely in the “Neue Weststadt” (see next chapter). Hence, the energy concept’s positive consequences such as low-priced green electricity were adopted incidentally.[3]

The information deficit’s downside is that more involved residents might engage more in energy saving and climate actions in other fields than these residents do. It should be mentioned that residents are interested in receiving better information. Knowing their own energy consumption is important to 89% of the residents. Still, 93% do not feel sufficiently informed (similar in Oesterreich 2015). A user interface realised for the “Neue Weststadt” as a mobile app will close this information gap in the future. In other fields of action, more effort should be undertaken to communicate with and engage residents in activities to transfer information and to increase individuals’ involvement.

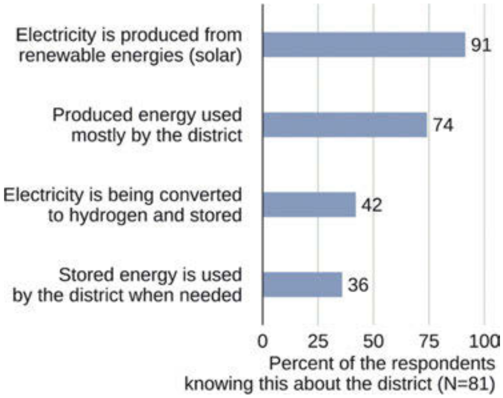

Figure 14.2: Residents’ limited knowledge of the district’s energy concept.

14.4.3 Few Complaints Related to the Concept of Climate Protection

Residents reported high levels of satisfaction with living in the “Neue Weststadt”. Measures of energy efficiency are mentioned positively by the residents. The underfloor heating is the fourth most frequently made positive comment, followed by the thermal insulation.

Most complaints expressed during our research are not related to topics of climate protection (similar findings in Stieldorf/Juri/Haider et al. 2001) but rather, e.g., about noise from the neighbourhood, the nearby railway tracks or ongoing construction, as well as limited availability of parking spaces in the area. Limited parking is a

3 For the tenants surveyed in another project by Schulze/Dietel/Engler (2018) on the other hand, the energy concept ranged among the top reasons for the decision to move in the particular house. Such a strong involvement probably influences usage and evaluation of the technology.

common concern in inner-city districts. From an ecological perspective, this deficit has the advantage to make personal car ownership less attractive.

The few partly climate-protection related comments refer to manual roller shutters on the windows and heat in summertime (Figure 14.3). This is related to the fact that saving energy in order to be less dependent on external electricity supplement is part of the energy concept. Therefore, no air conditioning and no electric shutters were implemented. To keep summer heat out, simple strategies like opening the windows during the night and closing the shutters during the day would help, especially in this well-insulated building. There seems to be an information gap the residents can be made aware of.

As a result of living in an energy-efficient block of flats, most residents (78%) expected lower energy costs, and 24% of these were disappointed with their performed saving. It seems, some respondents had quite unrealistic expectations on the potential of saving money for energy consumption or did not take into consideration that new technologies and innovative concepts are initially expensive. Overall, most residents had positive expectations for living in a climate district and found their expectations satisfied. The most common negative expectation was a higher rent (51%). Actual rents were in fact often perceived as high (67%), but rents result from living in a newly-built house in an attractive area, not from the energy concept. The rare worries directly related to the climate measures contained stuffy air (17%), annoying sounds of the ventilating system (11%), failure-prone technology (9%), and windows that cannot be opened (4%). The worries were only sometimes confirmed by the experiences of those few who shared it. Stuffy air was experienced by 7 of 12 respondents, annoying sounds of the ventilating system by 7 of 8, and failure-prone technology by 1 of 5. Most windows can also be opened. Temperature and air quality in the living rooms are rated as comfortable or very comfortable by 82%. In bed rooms, temperature (75%) and air quality (73%) are perceived fairly positive.

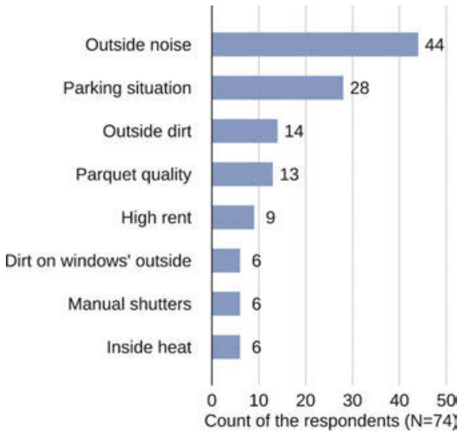

Figure 14.3: Complaints about flats or district entered as free text mentioned more than five times.

Overall, living in an energy-efficient house is evaluated more positively than in earlier projects (e.g. Stieldorf/Juri/Haider et al. 2001), and similar (e.g. Oesterreich 2015) or even more positively (e.g. Schulze/Dietel/Engler 2018, Joppien 2019) than in recent projects.

14.4.4 Living Well in the Climate District, No Concerns about Technological Innovations

Nearly all residents agree that one can live well in an urban climate district. 81% feel comfortable or very comfortable in their flats. 38% of the respondents are very satisfied with their flats and another 38% are rather satisfied. 34% rate the district as very good and another 44% as good.

Each household was offered a tenant rate for electricity, which was very well accepted. 98% of the respondents signed an electricity contract with the provider Polarstern to receive electricity mostly produced using solar panels on their roof. In fact, the tenant rate was a very reasonable offer. Green energy in the "Neue Weststadt" is considerably more favourable than the market price for electricity elsewhere in Germany. Still, only 27% state that it was very important for them to get the tenant contract from Polarstern. For most tenants, the electricity concept and its price simply fell in their laps and they are satisfied: 46% are very satisfied and another 41% are rather satisfied with the electricity provider.

Another important aspect in the evaluation of the success of the Esslingen climate district are potential concerns regarding hydrogen technology's safety and security. Hydrogen production is a rather new technique, especially when stored right below residential houses. Even with very strict safety regulations for hydrogen production and storage, residents might have subjective safety concerns regarding this unknown technology and its operation near their homes. The results indicate that such concerns do not exist widely and do not limit residents' support of the hydrogen technology. When asked about possible disadvantages of living in the "Neue Weststadt", nobody mentioned concerns about hydrogen in the free text fields. This result might be due to limited information or awareness, but even direct questions regarding the application of hydrogen technology revealed no severe concerns. To the contrary, 85% partly or fully agree that the development of hydrogen technology should be promoted more. Such development is happening right in their district. 75% agree that hydrogen is a very sustainable technology for energy storage. 69% consider the expansion of the network of hydrogen filling stations for cars useful. At the same time, 22% express safety concerns regarding hydrogen technology by rating it as still not well-developed enough. This general concern does not find expression in a rejection of its use in close proximity. Only 4% partly agree that they do not want a hydrogen filling station near their home (Figure 14.4).[4]

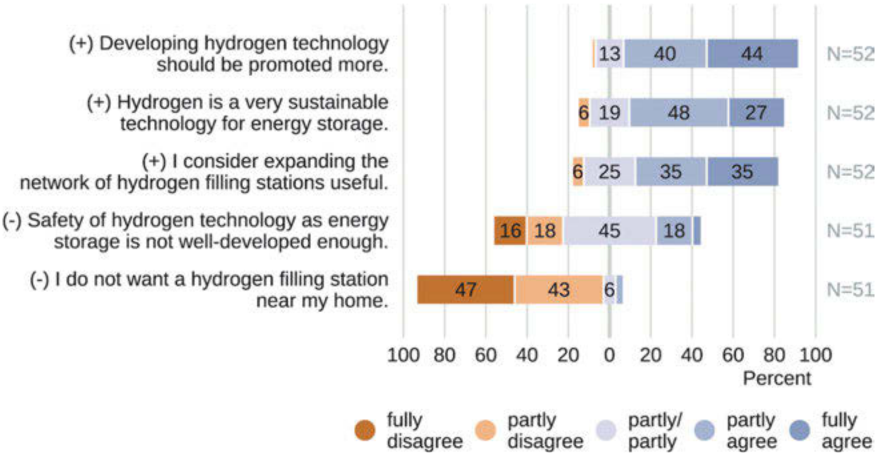

Figure 14.4: Residents widely support developing hydrogen technology as energy storage.

14.5 Conclusion

The purpose of social research in technological innovation projects is to monitor and evaluate residents' perception and acceptance of technological innovations and collect valuable feedback on the intersection of human and technology. Social research on energy transition monitors the "critical interrelationship between the physical and the cultural" (Rohracher 2005, p. 201). It is important to monitor residents' well-being and how they accept means of climate protection before innovative energy concepts are scaled up. Only when it is thoroughly monitored by social research, energy transition is ensured to be human-oriented and, thus, successful (Wüstenhagen/Wolsink/Bürer 2007, Rohracher/Ornetzeder 2008, Schulze/Dietel/Engler 2018). Accordingly, experts see scientific monitoring as a necessary tool in constructing and developing energy-efficient houses (Schulze/Gabriel/Dietel et al. 2017).

In case of the Esslingen climate district, residents expressed mostly positive feedback regarding their flats and the district. This confirms the success of the project creating a climate district worth living. In the climate district, there are living mostly highly educated, young professionals who were not fully aware of the district's en-

4 With a focus on mobility, Zimmer and Welke (2013) also found high acceptance for hydrogen technology. It was important for 63% of their respondents that hydrogen comes from renewable energies. And this is the case in the "Neue Weststadt".

ergy-innovative properties, especially in early stages of the project. Most of their positive or negative comments on their flats or the district are not related to the energy concept. Moreover, when pointed directly to the technological innovations, they were regarded positively. Fortunately, the production and storage of hydrogen in their immediate neighbourhood was not opposed by residents.

Some previous projects on energy-efficient housing were inhabited by volunteers who sought to contribute to energy transition by building an or moving into a pilot project on environmentally-friendly housing and were (potentially) willing to undergo losses of comfort (e.g., single-family house owners in Ornetzeder/Rohracher 2001 or Stieldorf/Juri/Haider et al. 2001, tenants in blocks of flats in Oesterreich/Zirk/Dietel et al. 2015 or Schulze/Dietel/Engler 2018). Results from such projects are hardly transferable to other target groups. The Esslingen results in contrast can be seen as a blueprint for other projects where people are rather selected by socio-economic status and by age, than by their a priori environmental attitudes. This is good news for other climate districts, because it allows to expect that residents in similar housing projects express similar acceptance of innovative technologies, as well as environmental attitudes and behaviour.

A potential limitation of our results stems from the demographic background of the climate district's residents. Other target groups of older, less educated, or less wealthy people might differ in their degree of acceptance of innovative technologies to make housing more climate friendly. Follow-up research projects should evaluate whether innovations like underfloor heating systems with low flow temperature, thermally well-insulated houses, and – most importantly – hydrogen production and storage close to the housing units are similarly well-accepted by residents with other demographic backgrounds.

Similar housing projects could profit from enhanced communication with residents and their more active participation in developing and establishing climate-friendly technical and organisational solutions that are suitable for everyday life. Firstly, we could expect more trust regarding technology, especially the production of hydrogen, if residents were better informed. Secondly, involvement and information could inspire residents to save energy and to try limiting their energy consumption in periods without sunshine. Lastly, receiving more feedback, engineers could learn more about users' needs and preferences to adapt technological implementation accordingly (Rohracher 2005, Rohracher/Ornetzeder 2008). More active user integration and cooperation would require new concepts of residents' participation (Löbe/ Sinning 2014). If users had the opportunity to contribute to decisions on the development of their district in group discussions and frequent feedback formats and polls, technological and organisational solutions would have a higher chance to find broader acceptance.

Overall, results display residents' overall wellbeing in the buildings and in the neighbourhood accompanied by strong environmental attitudes that– similar to most inhabitants in Germany – do not translate to higher environmentally friendly behaviour in everyday life. Yet, in a district advancing in energy transition, residents are constantly reminded of climate issues. This could be addressed more often to residents by communicating newsletters, postings, and by organising events to inform. A mobile app is about to be launched for the Esslingen climate quarter to inform the residents about their own and the other residents' energy consumption, and to communicate with property management. Using various ways to communicate, climate progressiveness can be transferred to new areas of action changing individual behaviour and community organisation, for example by increasing acceptance of car-sharing. People can subsequently become more willing to initialise and to develop concepts of common or shared space and to actively contribute to a sharing economy for other individual goods such as tools or urban gardening projects. Changes in other areas of life, such as consumption and nutrition, are possible and very much needed for our future on this planet.

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Bettina Dech-Pschorn, Gerhard Stryi-Hipp, Thomas Anton,
Frank Elberzhager, Rolo Fütterer, Christian Persohn

15 Integrated Research Approach of the Lighthouse Project EnStadt:Pfaff

Summary: The development of sustainable climate-neutral neighbourhoods requires new technical concepts and the willingness of stakeholders to develop and implement forward-looking solutions. In order to develop neighbourhood solutions that meet the major challenges such as climate change and the digitalisation of the working world, integrated technical solutions for the energy, mobility and digitalisation sectors are required on the one hand, and increased cooperation between the various stakeholders in the development of the forward-looking concepts on the other. In the EnStadt:Pfaff project, a comprehensive research approach was therefore chosen in which the most important elements of climate-neutral neighbourhoods and their interactions as well as the development processes are examined. Using the Pfaff Quarter as an example, technical concepts are developed, new technologies are researched and demonstrated, future requirements for neighbourhoods are investigated and development processes are analysed. The Pfaff Quarter is a 19-hectare former factory site in a central location of Kaiserslautern that is being developed into a residential and commercial area. The aim of the project is to derive recommendations for other neighbourhoods on how to proceed in order to achieve climate neutrality.

15.1 Motivation und Research Approach of EnStadt:Pfaff

New neighbourhoods and their buildings have to fulfil a multitude of requirements. At the time of their completion and for the following decades, they should offer their residents and users a demand-oriented and attractive living and working environment. Their conception must therefore be oriented towards the future needs that are to be expected in 10, 20 and 30 years. Demand forecasts are uncertain, but important trends such as the digitalisation of the working world and the ageing of society will undoubtedly have an important influence. Buildings and neighbourhoods must protect their res-

Bettina Dech-Pschorn, Stadtverwaltung Kaiserslautern, Referat Umweltschutz, Germany
Gerhard Stryi-Hipp, Fraunhofer Institute for Solar Energy Systems ISE, Energy System Analysis, Germany
Thomas Anton, Trier University of Applied Sciences, Environmental Campus, IfaS Institute, Germany
Frank Elberzhager, Fraunhofer Institute for Experimental Software Engineering IESE, Germany
Rolo Fütterer, Hochschule Kaiserslautern, FB Bauen und Gestalten, Germany
Christian Persohn, Christian Persohn Ingenieur- und Gutachtergesellschaft mbH, Germany

https://doi.org/10.1515/9783110777567-015

idents from environmental influences, including rising summer temperatures and extreme weather events, which will increase in strength and frequency. However, buildings and neighbourhoods also represent a not insignificant burden on the environment. In view of the already critical state of many ecosystems, the sealing of the landscape, the sinking of groundwater levels, the increasing extinction of species and other indicators, the environmental impact of the construction and operation of the neighbourhoods must be significantly reduced. For example, the development should provide natural areas, building materials should be recyclable and produced with low energy consumption, the energy demand should be low and the energy supply should be climate neutral. At the same time, social and economic objectives must also be met. In view of the housing shortage and high rents in many cities, for example, solutions are needed for low-cost construction and a social mix in the neighbourhoods.

The aforementioned requirements make the development of future-oriented neighbourhoods appear to be a very ambitious task. However, this does not only refer to the fact that the optimal technical solutions are difficult to identify, but also to the willingness and ability of the actors to develop and test new technical and design solutions. After all, seeking new solutions and possibly also changing planning procedures is more time-consuming than implementing the practised processes, requires new know-how and is associated with risks.

Designing a new neighbourhood with limited knowledge of future conditions and requirements is a familiar challenge for urban planners. Urban land use planning has always provided for the consideration and balancing of different interests and concerns, and complementary requirements have been regularly integrated. However, practice shows that the current challenges for sustainable neighbourhood development cannot be solved with gradual adjustments of existing solutions and procedures alone. Instead, new technical system solutions for infrastructures and buildings are needed, for example, to achieve climate neutrality and to tap into the advantages of digitalisation. But the development and planning processes must also be significantly further developed in order to cope with the growing diversity of aspects to be taken into account and the increasing complexity of technical systems.

The EnStadt:Pfaff project aims to show how a climate-neutral and sustainable neighbourhood can be developed, using the development of the Pfaff Quarter in Kaiserslautern as an example. In doing so, both the conception and planning of the quarter are supported professionally and innovative technical approaches to solutions are developed, demonstrated, tested and optimised. The focus is on the energy, mobility and digitalisation sectors, which will be strongly coupled in the future. However, not only the technical aspects are examined, but also the socio-economic challenges and success factors for the development of climate-neutral neighbourhoods, such as the influence of the process organisation, the changing needs of the users and the participation of the various stakeholders. Furthermore, economic and regulatory framework conditions that limit the possibilities for action are considered. Some megatrends and central requirements for sustainable neighbourhoods that can be derived from them are shown in Figure 15.1.

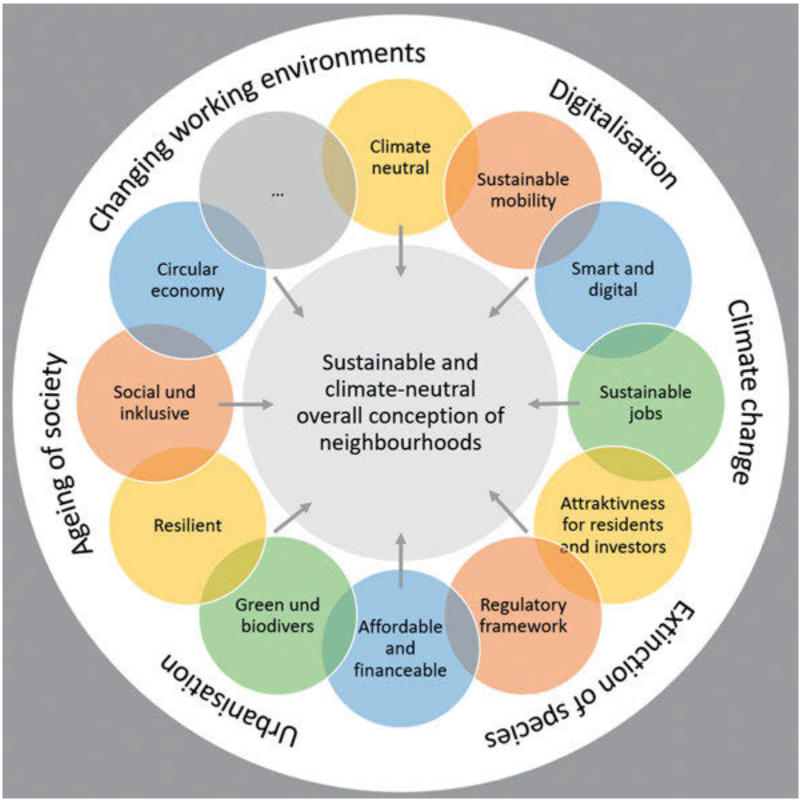

Figure 15.1: Megatrends and requirements for the development of sustainable neighbourhoods.

Research into neighbourhood developments requires Living Lab projects in which scientists work with local actors to develop new solutions. Technical components and subsystems can be developed in research laboratories and their use modelled. However, it is not possible to simulate which solutions are actually implemented in practice and which criteria were used in the selection process due to the high complexity of increasingly networked systems and the influence of non-technical factors. Experience shows that non-technical factors such as know-how, willingness to innovate and to take risks, participation of experts and the public, process organisation and political interests, possibilities for action and business interests of the actors as well as possible funding programmes and the regulatory framework play a central role in the selection of technical solutions.

In order to address the complexity of the issue, EnStadt:Pfaff has chosen a holistic research approach by accompanying both the planning and the first phase of implementation, developing technical solutions for the energy, mobility and digitalisation sectors and their coupling, and also investigating socio-economic issues. In favour of a holistic approach, a large number of research questions will be dealt with broadly, instead of going into great depth in a few questions. The focus is therefore not on the demonstration of especially innovative individual solutions, but on the integration of practical innovative components in a system context. The results of this holistic research approach are to be used to derive findings that are as generally valid as possible and can be transferred to other neighbourhoods.

15.2 Key Data of the EnStadt:Pfaff Project

15.2.1 Project Goals

The lighthouse project EnStadt:Pfaff aims to demonstrate how a climate-neutral energy supply for a neighbourhood can be achieved while maintaining a high level of urban development quality, using the Pfaff neighbourhood as an example. Specifically, the EnStadt:Pfaff project pursues the following goals in relation to the development of sustainable urban districts:

- Development of a future-oriented neighbourhood concept using the example of the Pfaff neighbourhood with solutions for a climate-neutral energy supply, sustainable mobility and user-oriented digitalisation.
- Research, development, demonstration and evaluation of innovative methods and technologies for the implementation of climate-neutral neighbourhoods.
- Development of post-industrial neighbourhood typologies and the resulting requirements for future neighbourhoods.
- Analysis of planning processes for neighbourhoods and development of proposals for the targeted development of sustainable urban neighbourhoods.
- Development of tools for the assessment and planning of neighbourhood solutions.
- Identification of success factors and development of recommendations for the successful development of climate-neutral neighbourhoods.

The results should help to ensure that climate-neutral neighbourhoods can be developed more quickly and in a more targeted manner in the future as an important contribution to the implementation of the energy transition in Germany.

15.2.2 The Pfaff-Quarter

The Pfaff Quarter is an industrial brownfield site near the centre of Kaiserslautern. The traditional Pfaff company produced sewing machines on the site for 150 years (Pfaff Sewing Machines 2022). After the company had developed into a global corporation after the Second World War, it experienced increasing economic difficulties towards the end of the twentieth century and had new owners several times. In 2009, production at the site was ended.

In 2014, the city of Kaiserslautern acquired 17 hectares of the total area of about 19 hectares to develop the neighbourhood (PEG GmbH 2022). Most of the site was built up with single-storey production buildings, all of which will be demolished. Several functional buildings such as the old and the new administration building, the gate, the former dining hall, the old and the new boiler house as well as the so-called Hansa building are to be preserved.

The redevelopment of the site is complicated by contaminated sites in the form of industrial waste, which arose in the course of the 150 years of sewing machine production and has partially found its way into the soil. Furthermore, explosive ordnance from the Second World War still has to be cleared as part of the soil remediation. Figure 15.2 shows the gate and part of the site in 1960 and the condition in 2018 after the soil remediation work has started.

Figure 15.2: View of the Pfaff site through the gate in 1960 (left) and of the boiler house, the old administration building and production buildings in 2018 (right).
(Source: Kaiserslautern City Archive, EnStadt:Pfaff / Trier University of Applied Sciences – IfaS)

15.2.3 Partners and Funding of the EnStadt:Pfaff Project

The EnStadt:Pfaff project started on 1 October 2017 and will run for six years after being extended by one year due to construction delays. There are 8 partners working together in the collaborative project (see Chapter 15.5). The project is managed by the Kaiserslautern city administration. Corporate partners are Pfaff-Entwicklungsgesellschaft (PEG), which is coordinating the development of the neighbourhood on behalf of the city, and Palatina Wohnbau, representing the property owners' groups of the two existing buildings involved. The research work is being carried out by the Fraunhofer Institute for Solar Energy Systems ISE, which is the scientific leader, as well as the Fraunhofer Institute for Experimental Software Engineering IESE, the University of Kaiserslautern, the University of Trier with its Institute for Applied Material Flow Management (IfaS) and the University of Bayreuth. (EnStadt:Pfaff 2022)

The collaborative project is funded by the Federal Ministry of Economics and Technology (BMWK) and the Federal Ministry of Education and Research (BMBF) within the 7th Energy Research Programme as a lighthouse project under the funding call "Solar Building / Energy Efficient City" with a total of about 23 million euros.

15.3 Work in the EnStadt:Pfaff Project

The EnStadt:Pfaff project is being implemented in a total of 31 work packages, each of which comprises individual tasks. An overview of the work packages is shown in Figure 15.3 and described below.

15.3.1 Concept of the Pfaff Quarter for the Target Year 2029

In the first work package, the basics for neighbourhood development were developed. This includes the development of the energy, mobility and ICT concept for the target year 2029. The energy concept development is described in Chapter 17: "Methods for the Development of Energy Concepts for Climate Neutral Neighbourhoods". When developing climate-neutral energy concepts, the fluctuations of renewable energies and sector coupling must be taken into account. In order to take this into account, a planning tool is being further developed in the project that can also be used for monitoring the neighbourhood in the future.

From a social science perspective, the influence of technical innovations as framework conditions for modern sustainable urban development is investigated. Post-industrial neighbourhood typologies for energy-efficient cities are to be derived from the observation of the Pfaff Quarter.

As a tool for the evaluation of neighbourhood concepts, a regional value-added calculator was developed, with the help of which the influence of certain characteristics of the neighbourhood implementation on the regional economic cycles can be determined.

Based on the concept developments, the development of the land-use plan for the Pfaff Quarter was actively accompanied, also through the creation of guiding principles. The findings from this process and recommendations for further development of urban land use planning for climate-neutral neighbourhoods are described in Chapter 16: "Need for further development in urban land use planning to enable climate-neutral districts".

15.3.2 Technology Demonstrators Neighbourhood Infrastructure

Since the Pfaff Quarter is not expected to be completed until 2029 and thus long after the planned end of the project in 2023, a core zone was defined in which individual technologies and solution concepts can be demonstrated and tested during the project

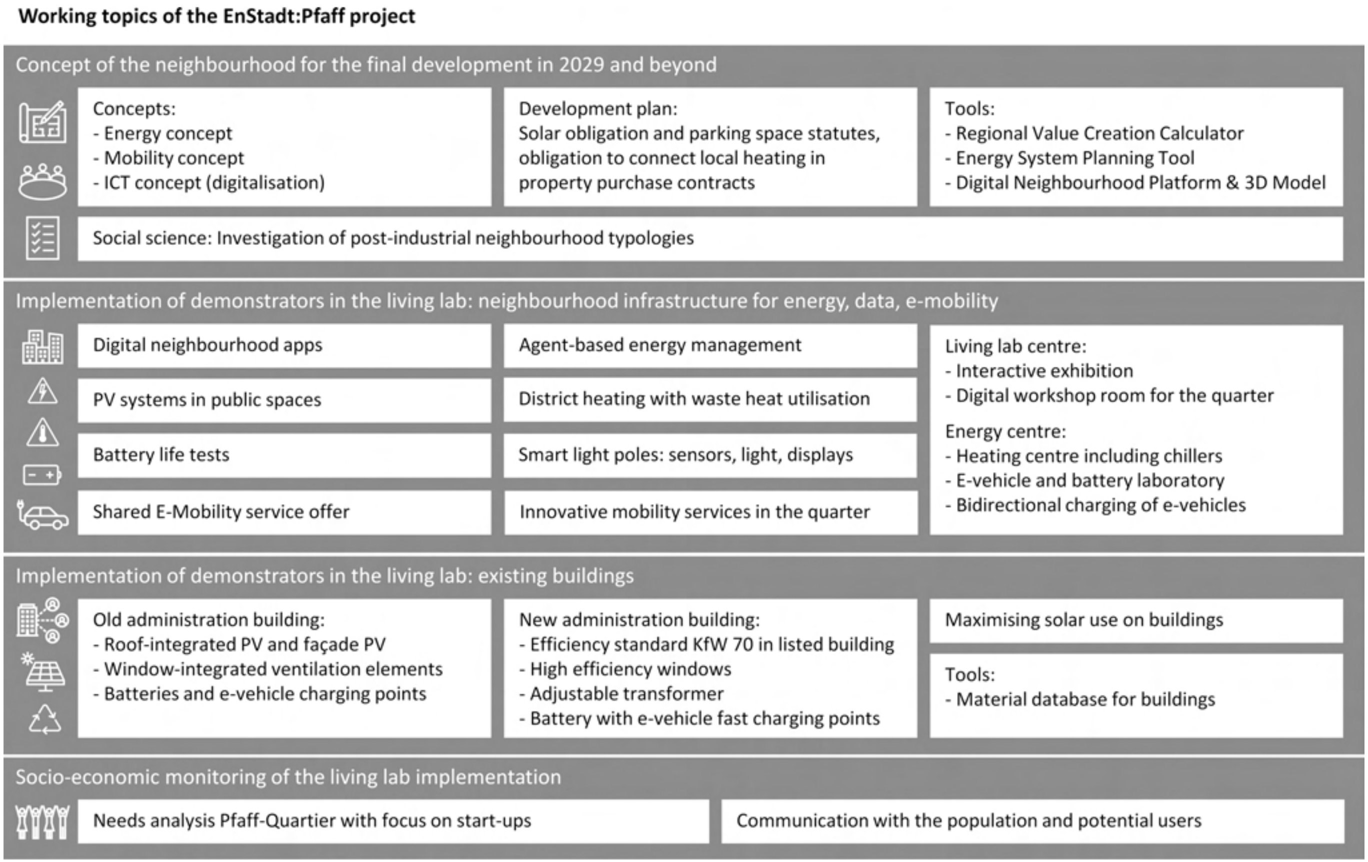

Figure 15.3: Overview of the working topics of the EnStadt:Pfaff project.

period. The two existing buildings whose owners are partners in the EnStadt:Pfaff project are also located in the so-called Pfaff axis.

Digital neighbourhood apps with various services are being developed for future residents and users. These are, for example, apps with playful suggestions for climate-neutral behaviour, for the use of multimodal mobility offers or for the support of neighbourly activities. The conception of the digital services is explained in detail in Chapter 19: “A climate-neutral smart city district supported by digital solutions”.

An efficient neighbourhood energy supply with the highest possible share of locally generated energy, i.e. solar power, is made possible through the exchange of electricity between the various consumers and producers in the neighbourhood. For this purpose, an agent-based neighbourhood energy management system is being developed that uses blockchain technology to organise the exchange and trade in an automated way. The tool was developed in the project, but since the regulatory framework conditions do not yet allow a neighbourhood-wide application, it can only be demonstrated within one building. Chapter 20:” Technologies for Climate Neutral Districts: Agent Based Energy Management and Blockchain Based Organization for Energy Communities” describes the tool in detail.

The energy concept shows that even if the solar potential within the neighbourhood is fully exploited, only part of the energy demand can be met. Therefore, a solar obligation was stipulated in the development plan to ensure that investors actually use the local solar potential on their buildings. In addition, it was investigated where PV systems could be installed in the public space and what additional potential could be tapped.

An important component of the energy concept is the local heating supply with waste heat utilisation. The implementation is accompanied by an examination of the practical obstacles to implementation. The use of waste heat from a foundry was planned. Among other things, the pipeline routing into the neighbourhood was examined, which is complicated due to the crossing of a road and a railway line, as well as the economic and contractual boundary conditions. After examination, the decision was made not to use the industrial waste heat, as the amount of heat that can actually be supplied is too small for economic implementation. This shows the necessity of a comprehensive examination of all aspects at an early stage. A local heating supply with reduced flow temperature is now being implemented in the neighbourhood, which is fed from the return flow of the district heat network, which will be decarbonised in the long term. In addition, the decentralised feed-in of waste heat from a large cooling machine is being demonstrated in order to investigate the use of decentralised waste heat sources, e.g. in the new commercial buildings or other low-temperature sources (heat pumps or solar thermal systems).

Batteries play an important role in the future energy system, especially for balancing the fluctuations of solar power generation. In order to investigate their suitability for practical use, service life tests of several battery types are being carried out and optimised modes of operation are being derived.

A high quality of stay in public spaces is an important goal of sustainable neighbourhood development. Smart light poles can contribute to this by carrying sensors, e.g. to measure air quality, traffic volume or noise, to control lighting according to demand or to provide information for visitors to the neighbourhood. Some applications will be demonstrated in the neighbourhood.

In order to communicate the findings of the EnStadt:Pfaff project to interested parties from Kaiserslautern and other cities in Germany, a living lab centre has been set up that will present important components of a climate-neutral energy system in an exhibition and provide space in a neighbourhood workshop to try out and develop digital solutions in workshops.

A newly constructed energy centre provides space for the heating centre, where the distribution of local heat and the feed-in of waste heat from the cooling machines takes place. It also houses an e-vehicle and battery laboratory, in which a DC power supply is installed that connects the PV systems on the roof and in the façade of the energy centre, the batteries and the e-vechicle DC charging station and other consumers on the DC side. This will be used to investigate the efficiency advantages of DC systems. In the laboratory, the bidirectional charging of e-vehicles and its contributions to the stabilisation of local energy systems with high PV shares are also being investigated in practice.

A special service offer for shared e-mobility will be developed for residents and users of the neighbourhood and integrated into the data platform. This IT-focused development is complemented by the development of concepts for innovative mobility offers in the knowledge that a low-car neighbourhood will only meet with acceptance if alternative mobility offers are sufficiently available and easily accessible.

15.3.3 Technology Demonstrators in Buildings

As part of the project, innovative technologies will be demonstrated on two existing buildings that will be renovated during the project period. In addition, general questions about building solutions will be investigated, for example how solar energy use on buildings can be maximised, also in combination with green roofs.

The listed New Administration Building is being converted into a medical care centre and although only interior insulation is possible, the high efficiency standard KfW-70 standard has been achieved. The energy concept is accompanied. Wooden integral windows with 4 glass panes and a blind in the outer pane cavity are demonstrated as components for high-quality building refurbishment, which meet the high requirements of summer and winter thermal insulation, sound insulation, satisfy the requirements of listed building protection and have a good ecological balance. The building is operated together with the neighbouring multi-storey car park and office building as an independent customer electricity grid in accordance with the German Energy Industry Act (EnWG). Electricity is supplied via two controllable transformers, which help to stabilise the power supply. Energy management is optimised with a battery and e-vehicle fast-charging poles.

On the Old Administration Building, a roof-integrated PV system is installed in the pitched roof and a solar façade with colour-matched PV modules in the façade. The innovative coating technology allows the PV modules to be colour-matched to the building with minimal reduction in the efficiency of the modules. Furthermore, window frame-integrated ventilation systems are demonstrated. Controlled ventilation in building renovations still poses a great challenge in practice, which is why the practical suitability of this technology, which is on the threshold of commercialisation, is being investigated. Furthermore, a battery and e-vehicle charging points are planned in the building.

Smart home applications and corresponding control elements represent the interface between the residents, the building management system and the neighbourhood energy system. They will therefore also be tested. Due to construction delays, the smart home systems will be demonstrated mainly in the exhibition.

The circular economy is also playing an increasingly important role in the building sector. A material database for buildings is an important tool for assessing both the grey energy bound up in the building and the recyclability of the building. Within the framework of EnStadt:Pfaff, such a database is being developed and the new administration building is being evaluated as an example. The tool is described in Chapter 18:" Greenhousegas Balancing and Life Cycle Analysis in the Context of Climate-Neutral Neighbourhoods".

15.3.4 Socio-Economic Monitoring of Neighbourhood Implementation

During the planning and implementation of the neighbourhood, the needs of future users will be recorded by means of surveys. According to the urban development plan, scientific institutes and technology companies are to be located in the neighbourhood. For this reason, the special needs of founders and start-ups are being investigated and what urban design can promote their settlement.

Communication with the population and potential users aims to inform them about the development of the neighbourhood and to enable their participation. Children and young people are also involved, for whom e.g. children's climate protection conferences are organised in the living lab centre. In addition, the needs of potential users are recorded and compared with the concrete plans.

The social scientific work in the living lab EnStadt:Pfaff is described in Chapter 21: "Learning from Climate-Neutral Neighbourhoods: Social Scientific Work in the Living Lab EnStadt:Pfaff".

15.4 Schedule of the Pfaff-Quarter Development

The development of a neighbourhood can be divided into four phases. The setting of objectives is followed by the establishment of a framework by the municipality, which essentially takes the form of urban land use planning. On this basis, the infrastructure and buildings are constructed, which can take many years depending on the size of the site. It is only during the subsequent operation of the neighbourhood that it becomes clear whether, for example, climate neutrality has actually been achieved. Further optimisations are also made during operation.

In February 2017, the city council adopted an urban development framework plan for the Pfaff Quarter as the basis for the creation of a development plan. This was adopted in 2020. The construction of the infrastructure and buildings is to be completed by 2029. After the start of the project in October 2017, the EnStadt:Pfaff project intensively accompanied the creation of the development plan. The energy and mobility concepts have been incorporated into the urban land use planning. Due to delays in soil remediation and site development, the new buildings will only be constructed after the end of the project. The innovative components of the EnStadt: Pfaff project are demonstrated on two existing buildings that were renovated during the project period. The timeline of the neighbourhood development and the phase of the EnStadt:Pfaff project as well as a possible monitoring phase afterwards are shown in Figure 15.4.

15.5 Project consortium

The EnStadt:Pfaff consortium consists of 8 partners from the fields of city administration, companies and research institutes (see Table 15.1).

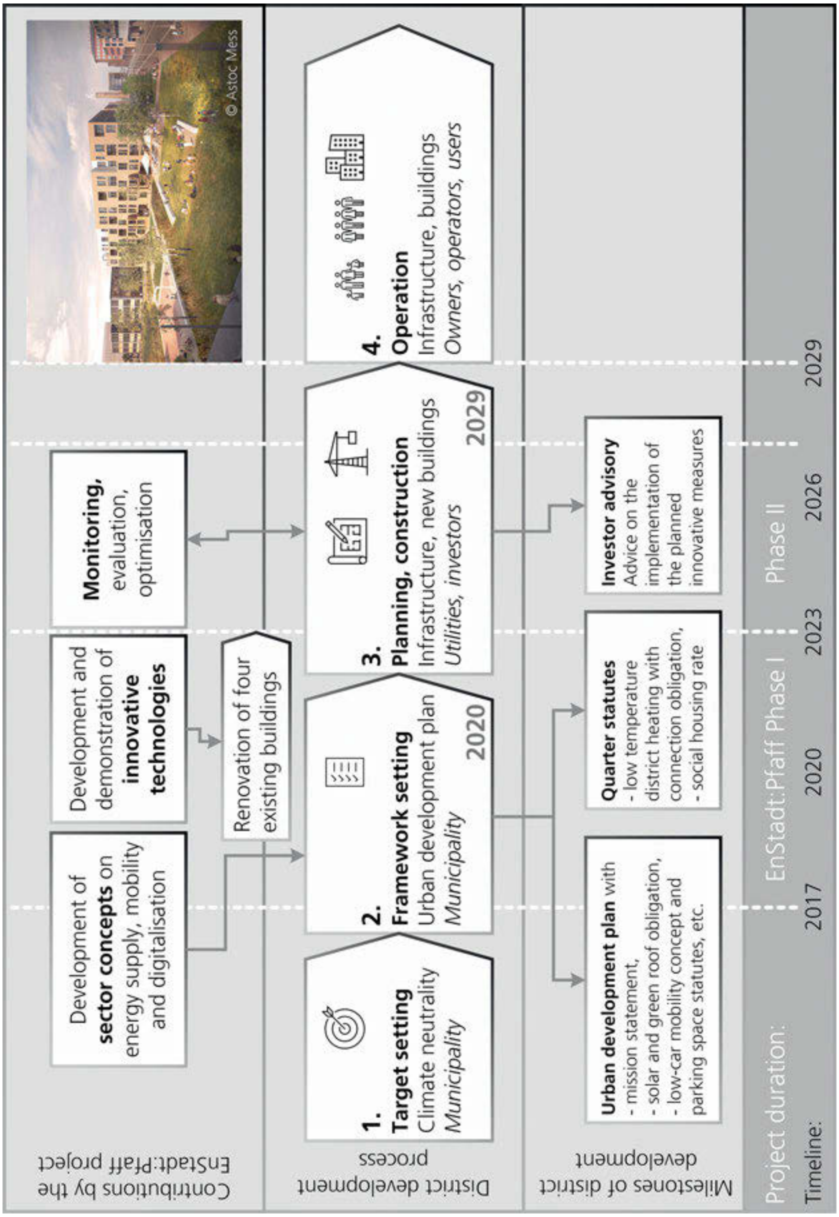

Figure 15.4: Development phases of the Pfaff Quarter with contributions from EnStadt:Pfaff.

Table 15.1: EnStadt:Pfaff project partners.

No	Short name	Name	Address
1	Stadt KL	Stadtverwaltung Kaiserslautern Kaiserslautern City Council	Rathaus Nord/ Lauterstraße 20 67657 Kaiserslautern
2	PEG	Pfaff-Areal-Entwicklungsgesellschaft Pfaff Development Company	Königstraße 154 67655 Kaiserslautern
3	Palatina	Palatina Wohnbau GmbH	Am Altenhof 11–13 67655 Kaiserslautern
4	Fraunhofer ISE	Fraunhofer Institute for Solar Energy Systems ISE	Heidenhofstr. 2 79110 Freiburg
5	Fraunhofer IESE	Fraunhofer Institute for Experimental Software Engineering IESE	Fraunhofer-Platz 1 67663 Kaiserslautern
6	IfaS	Hochschule Trier, Umwelt-Campus Birkenfeld Institut für ang. Stoffstrommanagement IfaS Trier University of Applied Sciences Environmental Campus, IfaS Institute	PO Box 1380 55761 Birkenfeld
7	HS KL	Hochschule Kaiserslautern Kaiserslautern University of Applied Sciences	Schoenstraße 11 67659 Kaiserslautern
8	UB	Universität Bayreuth University of Bayreuth	Universitätsstraße 30 95447 Bayreuth

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Gerhard Stryi-Hipp, Diana Berg, Bettina Dech-Pschorn, Rolo Fütterer, Patrick Huwig, Martin Kohl, Stefan Staehle

16 Need for Further Development in Urban Land Use Planning to Enable Climate-neutral Districts

Summary: Due to the increasing climate crisis and the stricter national and international climate protection targets, new neighbourhoods should be designed to be climate-neutral in the future. However, climate-neutrality can have a significant influence on urban design; energy planning must therefore take place in parallel with urban land use planning and thus earlier than before, and corresponding energy components must be included in the development plan. The challenges involved were determined in the EnStadt:Pfaff project, in which the preparation of the development plan for the Pfaff quarter was scientifically accompanied with the aim of achieving climate neutrality. As a concrete result, a guiding principle, a solar and green roof obligation and parking space regulations with mobility stations were included in the development plan. From the experience gained, it can be concluded that traditional urban land use planning in Germany must be further developed to enable the conception of climate-neutral neighbourhoods. This concerns a holistic and more balanced reflection of the objectives in the assessment processes, which are becoming increasingly complex. Therefore, it is proposed to describe the objectives in a guiding principle based on sustainability criteria in a holistic way. Further development is also required with regard to the urban land use planning processes, which should be designed more cooperatively in the future. Finally, suggestions are made as to how the municipalities themselves can change their urban land use planning processes and how the legislator can improve the framework conditions.

16.1 Introduction

Germany wants to become climate-neutral by 2045, and municipalities can make an important contribution to this by designing neighbourhoods to be climate-neutral in

Gerhard Stryi-Hipp, Fraunhofer Institute for Solar Energy, Energy System Analysis, Germany
Diana Berg, Bettina Dech-Pschorn, Stadtverwaltung Kaiserslautern, Referat Umweltschutz, Germany
Rolo Fütterer, Hochschule Kaiserslautern, FB Bauen und Gestalten, Germany
Patrick Huwig, University of Applied Sciences Trier, Environmental Campus, IfaS Institute, Germany
Martin Kohl, Fraunhofer Institut fuer experimentelles, Smart City Design, Germany
Stefan Staehle, Frankfurt University of Applied Sciences, Post-War Modernist Housing Research Lab, Germany

https://doi.org/10.1515/9783110777567-016

the future. Climate neutrality requires energy- and resource-efficient buildings, the use of local renewable energies and smart energy infrastructures, whereby individual solutions must be developed for each neighbourhood. Some of the technical solutions have to be taken into account in the development plan, which is why the climate-neutral energy system should be designed at an early stage in the preparation of the development plan. In a project of the German Energy Agency dena, a survey of various stakeholders active in neighbourhood development revealed "that the approach to climate-neutral neighbourhoods already differs significantly from standard approaches to neighbourhood development in the conception phase, especially due to the significantly broader development goals". One of the obstacles mentioned was that "traditional planning processes integrate energy planning too late" (Schmelcher/Kabakova/Katerbau et al. 2021).

In Germany, the creation of development plans is regulated in the Federal Building Code (BauGB). In these plans, resource-relevant aspects such as the extent and type of buildings, climate protection or traffic (e.g. parking spaces) can be legally defined (Verbücheln/Pichl/Bunzel et al. 2021). However, practice shows that traditional urban land use planning takes climate protection into account, but still allows urban planning solutions that are difficult to reconcile with climate neutrality, for example by making the use of solar energy more difficult. Therefore, there is a need for further development of urban land use planning with the aim of giving preference to measures that promote climate neutrality in the assessment processes and to prevent regulations that hinder it.

The current climate protection regulations in the BauGB date from 2011 (Bundestag 2011). According to § 1a paragraph 5 BauGB, the requirements of climate protection "shall be taken into account both by measures that counteract climate change and by those that serve to adapt to climate change". In the last decade, it has become increasingly apparent that climate change is having a dramatic impact on our way of life and is progressing much faster than previously assumed. As a result, there has also been a significant change in the political assessment of how to counteract climate change. In 2015, the United Nations agreed in the Paris Agreement on Climate Change to limit global warming to 1.5 °C if possible (United Nations 2015a), in 2021, the European Union has set the goal of becoming climate neutral by 2050 and Germany is already aiming for this goal in 2045 (BMWK 2021, European Commission 2021).

Since the climate protection regulations in urban land use planning are of a general nature, planners can, in principle, also take the now stricter climate protection targets into account in urban land use planning. However, as will be shown below, the goal of climate neutrality has a much stronger influence on both the provisions of the land use plan and the planning process than the previous climate protection goals. Therefore, the current approach of urban land use planning is not well suited to achieve climate neutrality of districts. For the successful planning of climate-neutral districts, urban land use planning should therefore be further developed by prioritising climate protection goals and making the planning processes more cooperative.

16.2 Planning Processes in District Development

16.2.1 Traditional Urban Land Use Planning

The authoritative instrument for spatial planning in Germany is urban land use planning, which is organised according to the legal regulations of the BauGB. Its purpose is to create legal certainty for all actors involved in building processes. The task of urban land use planning is to regulate the constructional and other uses of land in the municipality. The framework is to be established through a fair weighing of public and private interests. Land use plans are the zoning plan as a so-called preparatory Land use plan and the development plan as a binding Land use plan. The municipalities draw up the urban Land use plans as far as it is necessary for the urban development (§1 BauGB).

The zoning plan covers the entire municipality and serves the basic structural planning of the municipality. It depicts the intended land uses on an areal basis. It regulates, for example, the location of building areas, areas for utilities and the location of public and green spaces. A zoning plan is compulsory and forms the basis for the development plans in the municipality. It does not have a legally binding effect, but the cities and municipalities are bound by the specifications of the zoning plan when drawing up development plans. Figure 16.1 shows on the left as an example the land use plan of the city of Kaiserslautern.

Development plans are drawn up for small sections of a municipality and in each case contain the legally binding stipulations on the type and manner of building use of the land areas as well as the possible construction style. Furthermore, it can be specified how areas that are not to be built on are to be used. The Building Use Ordinance (BauNVO) specifies which specifications can be made in the development plan. The most important parameters for the degree of building use are the floor area ratio, which indicates the buildable area of a plot of land, and the number of full storeys or height of the buildings. The permissible location of buildings is also specified. **Figure 16.1** shows an example of the Pfaff quarter development plan in Kaiserslautern on the right.

Before the development plan is drawn up, a so-called urban development framework plan can be drawn up if, for example, the urban development is to be carried out under certain design aspects or the results of a public consultation are to be reflected in the planning process. The framework plan is a purely informal planning instrument that visualises, for example, suggestions from public participation or higher-level urban design issues. These include, for example, the dimensions and design of building masses, the design of street spaces, but also questions of materiality and spatial identity of urban quarters. Figure 16.2 illustrates the process of urban land use planning up to the implementation of building measures and classifies the framework plan as an optional element.

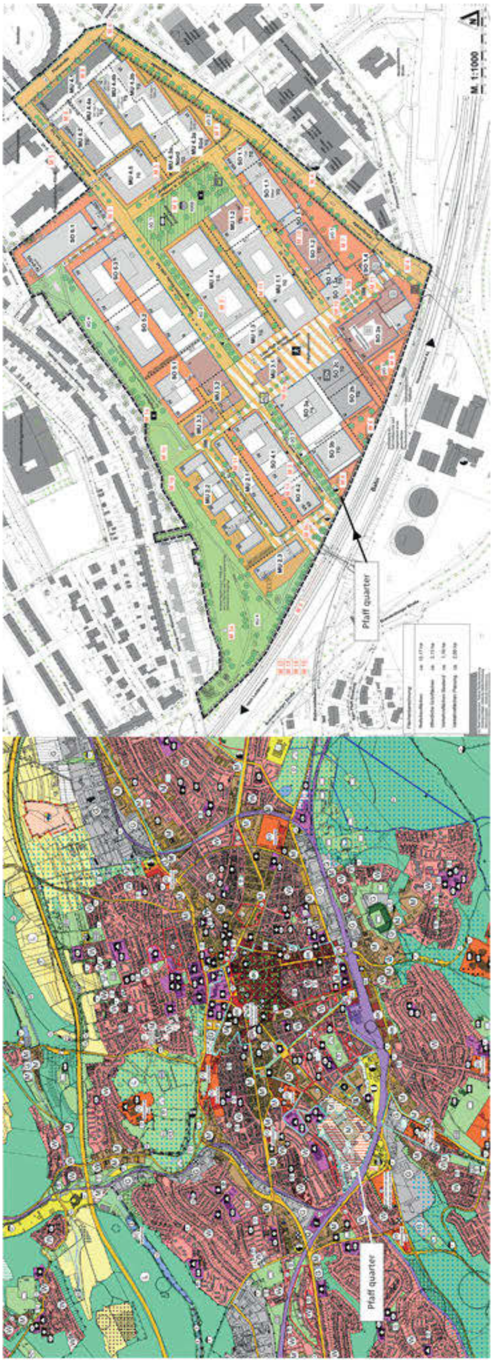

Figure 16.1: Section of the land use plan of Kaiserslautern city centre with Pfaff quarter (left) and Pfaff quarter development plan (right).

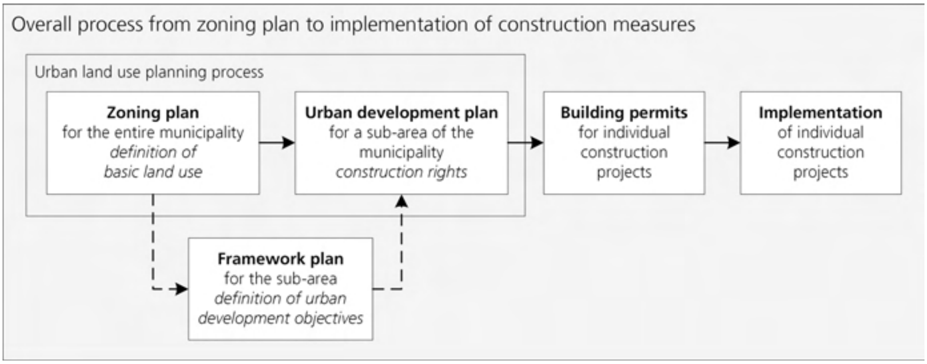

Figure 16.2: Steps from the zoning plan to the implementation of construction measures.

The development plan creates construction rights and provides the basis for the granting of building permits by the municipality. The usual process for drawing up a development plan is shown in Figure 16.3. The sequence of the preparation of the draft plan, the formal consultation of the public and authorities, and the decision-making by the decision-makers becomes clear. If there are significant changes to the draft plan during the process, participation must be repeated. The municipal council decides on the draft plan and can adopt amendments if necessary.

In the preparation of urban land use plans, public and private interests must be fairly weighed against and among each other. In accordance with the provisions of the Federal Building Code (BauGB), the requirements of healthy living and working conditions, the residential needs as well as the social and cultural needs of the population, the needs of the economy, mobility, the supply of energy and water in particular, the environment, building culture and environmental protection as well as other aspects must be taken into account. The urban land use plans are to ensure sustainable urban development which reconciles social, economic and environmental protection requirements, also in responsibility towards future generations. Furthermore, they are to ensure a socially just use of land that serves the common good, taking into account the housing needs of the population. The needs and requirements, some of which are in competition with each other, must therefore be assessed and evaluated in a comprehensive consideration process in order to find the best possible compromise.

Development plans are drawn up by the local planning authorities. The public, including children and young people, must be involved as early as possible. The public must be informed about the general aims and purposes of the planning, the main determinations and the probable impacts of the planning. The public must be given the opportunity to comment and discuss the planning (§3 BauGB). Furthermore, the authorities and other agencies of public concern whose area of responsibility may be affected by the planning must be involved by obtaining their comments on the draft plan and the statement of reasons (§4 BauGB). The consultation of the public and au-

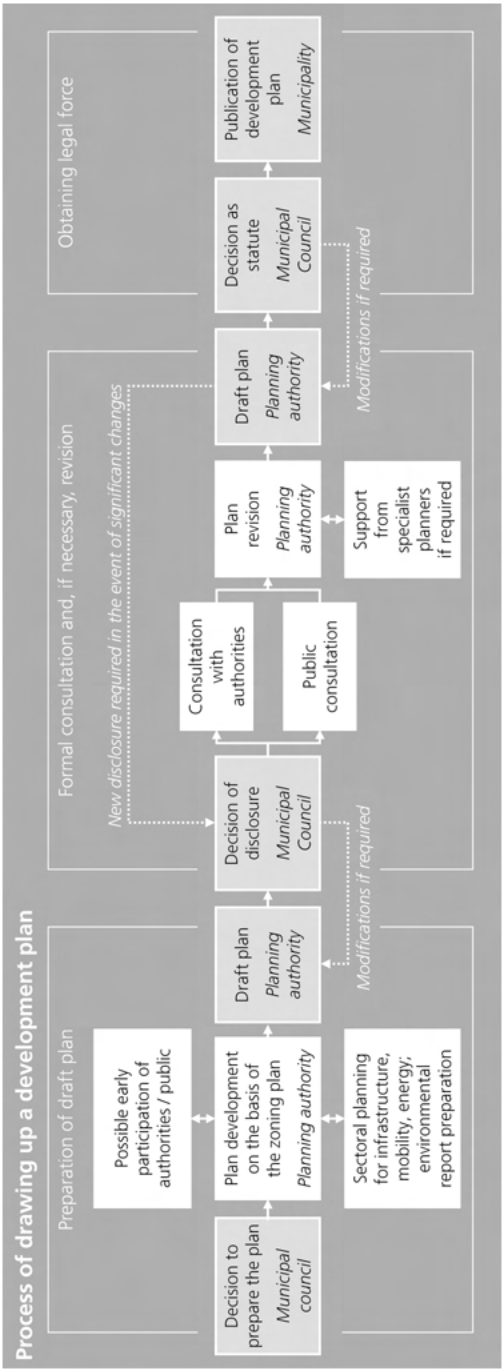

Figure 16.3: Usual process for the preparation of a development plan.

thorities serves in particular to fully identify all concerns that are affected by the planning and is intended to enable an accurate assessment. It also ensures that the public is informed (§4a BauGB).

Figure 16.4 shows an overview of the most important elements of the creation of a development plan. With regard to the objectives, a distinction must be made between the general requirements of the national building code and the concrete objectives of the municipality. The development plan must be accompanied by an explanatory memorandum stating the objective, purpose and main effects of the development plan, as well as an environmental report prepared on the basis of an environmental assessment (§ 2a BauGB). The overview makes it clear that this is an extensive compilation process with a complex result.

The scope of action of the municipality in the context of urban land use planning is limited by the fact that all determinations must be justified in terms of urban development. As a consequence, cities, for example, point out "that the energy objectives in the development of new building areas could not be achieved by way of determina-

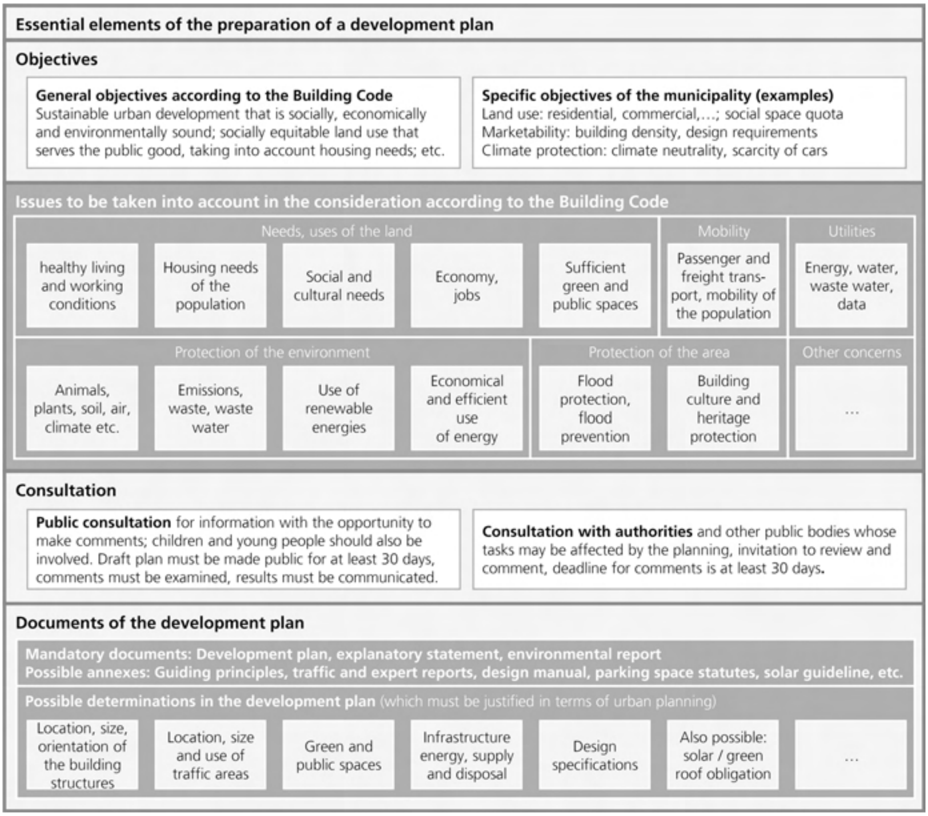

Figure 16.4: Essential elements of the preparation of a development plan.

tion in the land use plan" (Bunzel/ Frölich v. Bodelschwingh/Michalski 2017). This also highlights the need for further development of urban land use planning.

16.2.2 Need for Further Development in Urban Land Use Planning

In the EnStadt:Pfaff research project, the need for change in urban land use planning with regard to the development of climate-neutral neighbourhoods was examined using the example of the Pfaff quarter in Kaiserslautern. The Pfaff quarter is an industrial wasteland where sewing machines were produced by the Pfaff company for 150 years. The 19-hectare site is to be developed into a mixed-use area with residential and commercial buildings. The development plan was drawn up between 2017 and 2020 and the process was closely accompanied by EnStadt:Pfaff with the aim of achieving climate neutrality for the quarter. It was found that it is difficult to anchor climate neutrality in development plans within the framework of traditional urban land use planning. Among other things, the following challenges were identified that make the development of climate-neutral land use plans difficult:

1. **Energy issues are considered too late in the planning process.**
   In the traditional process of land use planning, energy planning is usually done at a stage when important cornerstones of the plan have already been determined, e.g. the number, size, orientation and use of buildings as well as the use of open spaces. This can limit the availability of land for measures to achieve climate neutrality, e.g. for the use of renewable energies.
2. **There is a lack of a clear definition of the term "climate-neutral development plan".**
   Whether the development plan enables or at least does not hinder climate neutrality is not easy to determine, as clear definitions are lacking.
3. **There is no assessment and proof that the development plan is suitable for actually achieving climate neutrality.**
   Climate neutrality can usually be achieved in various ways and requires the interaction of a wide range of measures. This makes it difficult for decision-makers and the public to assess how well the development plan is suited to achieving climate neutrality. So far, there is no report required that assesses this in a well-founded way and presents the results.

The necessity of early integration of energy and comprehensive mobility planning into urban planning in order to achieve the goal of climate neutrality has been identified in many other studies. For example, early coordination of specialist interests within the city administration and early involvement of the local energy supplier is recommended (Bunzel/Frölich v. Bodelschwingh/Michalski 2017) and the accompanying preparation of an integrated energy concept are recommended as well (KEEA/IWES 2014). A similar finding emerges in an international comparison. In Annex 63 of the International Energy Agency's (IEA) EBC programme, it was determined that only in 2 out of 11 countries studied, namely in Denmark and the Netherlands, energy planning takes place in parallel with and is combined with urban planning (Church/Quitzau/Hoffmann et al. 2017).

16.2.3 Interface Between Energy and Urban Land Use Planning

Climate-neutral energy systems are characterised by decentralised energy generation and a corresponding energy infrastructure. Some of the components are relevant to the development plan due to their land requirements. Since solar energy is usually the most important renewable energy source in urban districts, the development plan must ensure that the installation areas on the building roofs and façades are shaded as little as possible. In order to ensure that all available and suitable roof areas are used for solar energy generation, a solar utilisation obligation can also be included in the development plan, as is the case in the Pfaff quarter in Kaiserslautern (Stadt Kaiserslautern 2020b). Land must also be made available for the use of geothermal energy or waste heat from groundwater, for example.

The efficient and economical use of energy requires, among other things, a high efficiency of buildings. The requirements for this are basically defined at national level, but the municipalities can tighten the requirements. However, the municipalities usually regulate this in private-law property purchase agreements. For example, the city of Heidelberg has only permitted buildings in accordance with the passive house standard in the new Bahnstadt district. On the basis of an energy concept, the municipal council concluded an urban development contract with the project developer, on the basis of which the energy requirement of the Passive House Standard was included in the purchase contracts with the investors and builders (Bermich 2012).

Climate-neutral energy systems usually require a more extensive energy infrastructure, for which areas must be designated in the development plan. These can be large, seasonal heat or cold stores, which can be implemented above ground or as underground storage. In most cases, the number of transformer stations is increased to accommodate the large photovoltaic capacity and to enable the charging of electric vehicles. Electricity, heating and cooling networks are not included in the development plan, but areas for an energy centre must be provided. This can also be larger if a neighbourhood battery store or a hydrogen electrolyser is to be installed.

Figure 16.5 lists possible components for climate-neutral energy systems in a district and shows whether they can be relevant for the development plan. These include components for which land must be specifically designated or the prohibition of decentralised combustion of biomass for emission reasons.

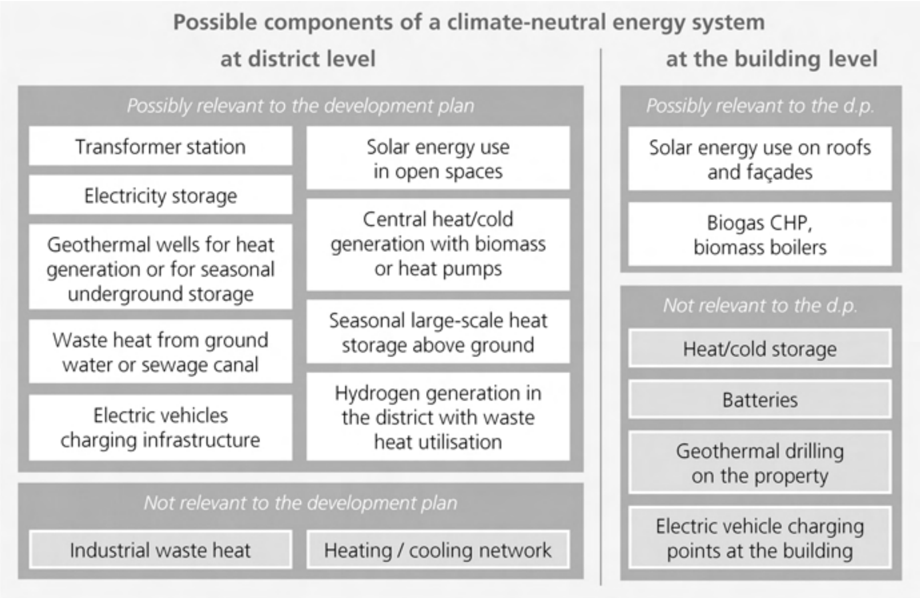

Figure 16.5: Relevance of possible components of a climate-neutral energy system for the development plan.

16.2.4 Interface Between Mobility and Urban Land Use Planning

The mobility sector must also make an important contribution to the goal of climate neutrality. Especially in urban areas, where the driving demand is mainly for short to medium distances, electric mobility will dominate in the future. This is because electric motors have a higher tank-to-wheel efficiency (73–90%) than internal combustion engines (16–37%) over all relevant engine loads and speeds (Weiss/Cloos/Helmers 2020). This means that just by switching from combustion to electric vehicles, primary energy consumption can be reduced by 50% to 82%. In addition, the electricity for charging the e-vehicles can easily be provided with renewable energies and the controlled charging of the e-vehicles can be integrated into the energy management. Accordingly, the construction of a charging infrastructure for e-vehicles must be provided for in new neighbourhoods and taken into account in the development plan. However, a sustainable mobility concept goes far beyond the energy consumption of the vehicles. It also pursues the goal of partially displacing motor vehicles from public space and thus creating more space for other types of mobility such as walking and cycling and other open space with a better quality of life.

Future-oriented mobility concepts are multimodal and integrate individual transport with the mobility forms of the environmental network such as public transport or car and bike sharing services. A shift to non-motorised mobility is achieved, for example, through the city of short distances, which has been called for as a concept since the 1980s and aims at a city on foot. However, this has so far only been implemented to a limited extent outside the inner cities (Schöneberg 2019). Instead, urban planning is often still oriented towards the model of the car-friendly city from the 1960s (Topp/Huber-Erler 2014).

The intended mobility concept is reflected in the urban land use planning through the designation of traffic areas for moving and stationary traffic. Since the mobility conditions are thus fixed for decades, they are highly relevant. In the urban development framework plan for the Pfaff quarter, the goal of a "low-traffic area" was adopted (ASTOC/MESS 2017). Within the framework of the EnStadt:Pfaff project, this goal was then concretised as a "low-car district" (Stadt Kaiserslautern 2020a). This is to be achieved through the provision of good public transport services, car and bike sharing offers and good accessibility with footpaths and cycle paths. To this end, seven mobility stations with car and bike sharing parking spaces are planned in the quarter, so that the maximum distance to a mobility station is 150 metres. The internal traffic development is provided by partially traffic-calmed streets. Only a small number of car parking spaces are planned in the public space; the necessary public car parking spaces are accommodated in two neighbourhood garages. Private parking spaces are located in underground garages or in the neighbourhood garages. By displacing stationary car traffic, the public space is increasingly available for pedestrian and bicycle traffic as well as for recreation and meeting.

In the Pfaff quarter in Kaiserslautern, a car parking space regulation, which has been further developed into a mobility regulation, serves as an instrument for controlling the density of cars and was adopted as a supplement to the development plan (Stadt Kaiserslautern 2020e). This restricts the number of parking spaces that actually have to be created due to the offers for alternative forms of mobility. Compared to the parking space regulations otherwise applicable in the city, the number of parking spaces in the quarter must be reduced by 40% for residential buildings and by 25% for other buildings. The building owner must pay the city a compensation fee for the parking spaces that are not to be provided. The city uses the revenue to finance mobility services such as mobility stations. Since the payment amount of currently 8,400 EUR per parking space is significantly lower than the costs for the construction of an underground parking space with approx. 35,000 EUR, the "payment for sustainable mobility" reduces the costs for the building owner and thus also the tenants and at the same time improves the public mobility offer without burdening the city budget.

16.3 Development of a Guiding Principle

The interactions of urban planning, energy, mobility and other dimensions of district development are significantly higher in sustainable and climate-neutral districts than in traditional districts. This complicates the consideration processes in urban land use planning, as hardly anyone can keep track of all disciplines and evaluate competing approaches. Obtaining even more sector-specific expert opinions, e.g. with the task of examining the interaction with other sectors, could help somewhat here. However, this increases the effort significantly and still does not provide an interdisciplinary overall assessment of the concept. For example, neither an energy expert will be able to professionally assess an urban design nor an urban planner an energy concept. Planners and decision-makers must therefore compare and weigh up the assessments of different sectors on the basis of their own expertise, which is probably too much of a challenge in some cases.

Guiding principles do not solve this problem, but they do alleviate it. If decisions cannot be made on a professional basis, traditional solutions are usually chosen or particular interests prevail. Guiding principles counteract this. The formulation of objectives and the joint coordination of the system of objectives promote mutual understanding of the respective sector-specific interests and enable the derivation of cross-sectoral evaluation criteria.

In traditional urban land use planning, the creation of a holistic guiding principle is not envisaged, as the urban development goals are in the foreground. In the past, energy objectives were limited to the question of which infrastructure would best ensure the supply of the neighbourhood from the outside. Environmental goals have so far only been environmental protection goals, which are intended to protect the environment from excessive degradation, i.e. to prevent excessive destruction of natural habitats and resources. Designing environmental goals, e.g. shaping the habitat of animals and plants through urban planning measures and improving their quality, have not been taken into account so far.

A guiding principle for a sustainable, climate-neutral neighbourhood, on the other hand, pursues a holistic approach and describes goals and visions for all dimensions of an urban development measure. The goal must be to create neighbourhoods with a high quality of life and amenities that are in harmony with nature and natural cycles. The United Nations' Sustainable Development Goal 11 provides guidance: "Make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations 2015b). It is obvious that ecological, economic and social sustainability, which also includes climate neutrality according to today's knowledge on climate change, can no longer be achieved within the framework of the hierarchically designed assessment methods of traditional urban land use planning. This is because the urban development concept is strongly influenced by the other objectives and should in future be understood as an equal and no longer superordinate development objective. It is therefore advisable to make the sustainability goals themselves the core of the urban development concept. The German Sustainable Building Council formulates this as follows: "accordingly, neighbourhood planning should be oriented towards sustainability criteria in the most holistic way possible" (DGNB 2022).

The Association of the Real Estate Industry also states: “the central prerequisite for sustainable neighbourhood development is clear guiding principles, goals as well as integrated urban and neighbourhood development concepts and strategic planning for the city and the neighbourhood” (ZIA 2014). It further points out: “Thematic diversity such as energy and mobility concepts, residential environment design or infrastructure supply requires a cooperative partnership between all actors. A jointly developed guiding principle is a good orientation for this process in order to achieve a broad understanding.” (ZIA 2020).

16.3.1 Contents and Process of Creating a Guiding Principle

Guiding principles consist of a preamble, which presents the framework conditions and overarching objectives, and of individual key sentences, which summarise the core statements on the objectives for each topic in one or two sentences (Genz/Reick/Schambortski et al. 2005). The objectives should be formulated as concretely, practically and comprehensibly as possible in order to provide clear orientation. The objectives should also be measurable in order to be able to check the achievement of the objectives in the consideration process of the plan preparation. The guiding principles should include all relevant objectives of neighbourhood development.

A guiding principle must be consistent in itself and the objectives of the individual sectors must not contradict each other. The creation of a guiding principle must therefore be moderated. Experience has shown that the desired broad participation of stakeholders leads to a multitude of opinions and extensive discussions of detailed issues. The justified concerns must be taken up without getting lost in details and compromise formulations acceptable to all sides must be worked out. This is the task of a moderator who has professional competence, experience in moderation and acceptance by the participants. This could be someone from the administration, an external service provider or someone from academia.

The development of guiding principles requires clear governance. The municipal council should initiate the process and determine who will lead the process, who will be involved and who will make the decisions in the process. For example, it would be useful to form a small core group to carry out the editorial work and revise proposed wording. The final guiding principles should be adopted by the municipal council, as this sets the framework for the evaluation of the draft development plan.

16.3.2 Guiding Principles for the Pfaff Quarter

In the EnStadt:Pfaff lighthouse project, it became apparent at the beginning that the eight project partners partly had different or only vague ideas of goals regarding the targeted climate-neutral Pfaff quarter. For this reason, it was decided in spring 2018 to develop a mission statement for the Pfaff district from the perspective of the EnStadt:Pfaff research project. After intensive discussions and coordination processes, the consortium was able to unanimously adopt the guiding principles in January 2019. In the preamble, particular reference is made to the overarching objectives of the Sustainable Development Goals of the United Nations (United Nations 2015b). A motto was defined for each of the following six thematic areas and 4 to 10 guiding principles were formulated:

- for the Pfaff quarter as living and working space: creativity and quality of life
- for buildings: architectural quality and energy production
- for energy: climate neutrality and a high degree of self-sufficiency
- for mobility: resource protection and quality of life
- for digitisation: user-oriented and future-oriented
- for participation and education: information and transparency

The guiding principles of the research project were also considered helpful by the urban planning department and, with minor changes, were proposed to the municipal council as an annex to the development plan for resolution. On 25 May 2022, after a second disclosure, the council adopted the development plan including the guiding principles (Stadt Kaiserslautern 2020d).

Guiding principles, once developed and adopted, usually find a high level of acceptance; the challenge lies in their creation. For the Pfaff quarter, the guiding principles were developed within the framework of the research project, which was a significant facilitation because the human resources and working structures were already in place for their development. As they were only conceived as project-internal guiding principles, no external actors were involved in their creation. The fact that the project-internal guiding principles were adopted by the administration and politicians in the end was not originally planned but demonstrates the consortium's good understanding of the expectations of sustainable neighbourhoods based on the close cooperation in the conception of the neighbourhood with the stakeholders in Kaiserslautern.

Under the usual conditions, it is recommended that representatives of all relevant stakeholder groups, i.e. from politics and administration, the real estate industry, utilities and civil society, be involved in the creation of guiding principles for neighbourhood development. This increases the effort but is an important basis for public acceptance.

The guiding principles for the Pfaff quarter were developed in parallel to the development of the land use plan and thus only indirectly influenced it. However, its inclusion as an annex to the development plan provides orientation for the future implementation of construction measures by property owners by communicating the municipality's objectives for the neighbourhood. This is therefore a further, not insignificant function of guiding principles.

16.4 Integrated Urban Land Use Planning in the Pfaff Quarter

16.4.1 Preparatory Work for the Development Plan

The urban land use planning for the conversion of the Pfaff site has a long history, which began back in 2007 with an initial city council resolution to draw up a development plan, on the basis of which a redevelopment concept was developed. After that, the process came to a standstill. Within the framework of a European competition, new impulses for neighbourhood development were developed and in 2016 a first public participation was carried out within the framework of the so-called “Pfaff Workshop”, in which a catalogue of criteria for the Pfaff site was developed. In parallel, the ASTOC/MESS planning consortium developed an urban development framework plan, which was adopted by the municipal council on 20 February 2017 (ASTOC/MESS 2017).

On the 18-hectare site, the creation of an urban quarter with mixed use was envisaged with approx. 60% office, service, research, development and culture, approx. 10% commercial and approx. 30% residential. Buildings with a gross floor area of 218,300 m^2 are to provide space for about 1,400 residents and about 3,200 jobs. The development of the quarter is to be sustainable and low-traffic, and the original character of the quarter is to be preserved by retaining and integrating existing buildings. The framework plan was updated in February and November 2018. An overview of the development process is provided by (EnStadt:Pfaff 2022).

16.4.2 Preparation of the Development Plan

The preparation of a development plan for the Pfaff site was carried out in the steps described in Chapter 16.2.1. The city council passed a resolution on 15 May 2017 to prepare a development plan. A first draft plan was prepared on the basis of the framework plan and the results of the public consultation. The city council approved the draft plan and decided to publish it on 12 November 2018, adding a minimum social space quota of 20% to the draft. An environmental report, a traffic assessment and a market and location analysis, a design manual to ensure the architectural quality of the neighbourhood and a parking space regulation were attached (Stadt Kaiserslautern 2018).

The disclosure for formal public consultation took place from 3 December 2018 to 25 January 2019. Seven comments were received during this period. In its statement, the EnStadt:Pfaff research project advocated, among other things, the introduction of a solar obligation in combination with the already planned obligation to install green roofs on the flat roofs of new buildings. Since, due to the high building density, only approx. 35% of the neighbourhood's electricity demand can be met by fully utilising the available roof area potential for solar power generation in combination with green roofs, it was argued that this potential must be fully tapped in order to achieve climate neutrality. Furthermore, it was also recommended to allow the façade surfaces to be used for solar energy (EnStadt:Pfaff 2019).

The solar obligation and other changes were incorporated into the plan by the city planning department. As these are fundamental changes, the city council decided on 28 October 2019 to carry out a new public and authority consultation for the updated draft plan (Stadt Kaiserslautern 2019). The previous appendices were supplemented by a solar guideline as an explanation of the solar obligation and the guiding principles for the Pfaff quarter. In addition, a revised version of the parking space statutes was attached with the reduction of parking spaces shown in Chapter 16.2.4.

The new disclosure took place from 18 November 2019 to 20 December 2019. Six comments were received from the public and others from the authorities. After incorporating the amendments, the final draft of the development plan was discussed by the city council on 25 May 2020 and adopted (Stadt Kaiserslautern 2020c). After approval by the county administration, the development plan became legally effective on 12 September 2020 as shown in Figure 16.6.

The development plan for the Pfaff quarter enables a climate-neutral energy supply for the quarter. Good solar utilisation on the building roofs was made possible by largely avoiding shading. A solar installation obligation on all roofs in combination with the green roof obligation was specifically included. The installation of solar systems is also possible in the façades. In the mobility sector, a reduced number of parking spaces is planned in the public space and the associated parking space statutes allow for the construction of mobility stations. With regard to the energy infrastructure, several transformer stations, a heating centre, a district heating transfer station and a solar charging station for electric vehicles are integrated into the plan. The energy concept with central local heating supply is described in the explanatory memorandum, but a compulsory connection to and use of district heating is not part of the development plan, but is included in all property purchase contracts on the basis of a city council resolution (Stadt Kaiserslautern 2021b). The list shows that the development plan only contains some components of the future energy supply system, but it would be difficult to achieve climate neutrality without these stipulations, which underlines their importance.

Figure 16.6: Legally binding development plan for the Pfaff quarter in Kaiserslautern.

16.5 Recommendations for the Planning of Climate-Neutral Districts

16.5.1 Cooperative Planning Processes

There is a need for further development of urban land use planning with regard to the stronger consideration of sustainability aspects, including climate neutrality, in the development plans. What is needed is earlier energy planning and consideration in the plan of the energy-related land uses identified as a result. However, the need for further development also relates to the preparation process. Only changes in the procedure can ensure that holistic and balanced solutions are found and sustainable neighbourhood concepts are successfully developed.

The development of a sustainable, climate-neutral development plan requires a cooperative approach. The interactions of the most diverse aspects of urban land use planning, such as compactness of buildings, structural density, urban planning quality, use of public space, traffic routes and mobility offers, economy, social issues, freedom of ownership and resilience, increase the complexity of plan development and the necessary consideration processes. For example, energy supply structures interact directly with building design, which is why energy and urban planning should not be organised sequentially, but in parallel and cooperatively. There is a need for increased cooperation between urban planners and external experts, as well as within the departments of the city administration. The German Association of Cities states with regard to climate-friendly urban planning: “The implementation of the consideration results in the sense of the integrated urban development concepts requires an organisational structure in the cities that facilitates interdepartmental cooperation” (Bagner/ Kiel/Klöppel et al. 2022).

Figure 16.7 illustrates the development of a climate-neutral development plan using different procedures. In the traditional process, the urban design is created first and then an energy concept is fitted to it. If this does not lead to the desired effect, the process starts again by revising the urban design. This process is very time-consuming. If integrated at an early stage, the development of the urban design and the energy concept take place in parallel, and the mutual adjustments take place in several iteration loops. This shortens the process, but does not yet lead to optimally integrated solutions, as the sectors work in silos.

A cooperative development process is therefore recommended, in which the urban development concept and the energy, mobility, climate protection and climate adaptation concept are not only developed in parallel but, as far as possible, together. The experts from the energy, mobility and environmental sectors should also contribute suggestions for the design of the urban planning concept in order to align it with the sustainability goals in its conception. This requires the opening of the planning process by the planning authorities and the active involvement of non-urban planning stakeholders in a co-creation process. This represents a significant change in the way we have worked so far, but it is probably the only way to achieve optimally integrated development plans.

16.5.2 Recommended Actions

In summary, the following concrete measures for the further development of urban land use planning can be derived from the previously presented content-related and process-related needs for further development of urban land use planning, which can be implemented by the municipalities themselves:

1. Concretisation of the objectives system by the creation of guiding principles

At the beginning of the land use plan procedure, guiding principles should be drawn up that describe the objectives of the various dimensions of the district. The guiding principles can also be the result of an early public involvement process.

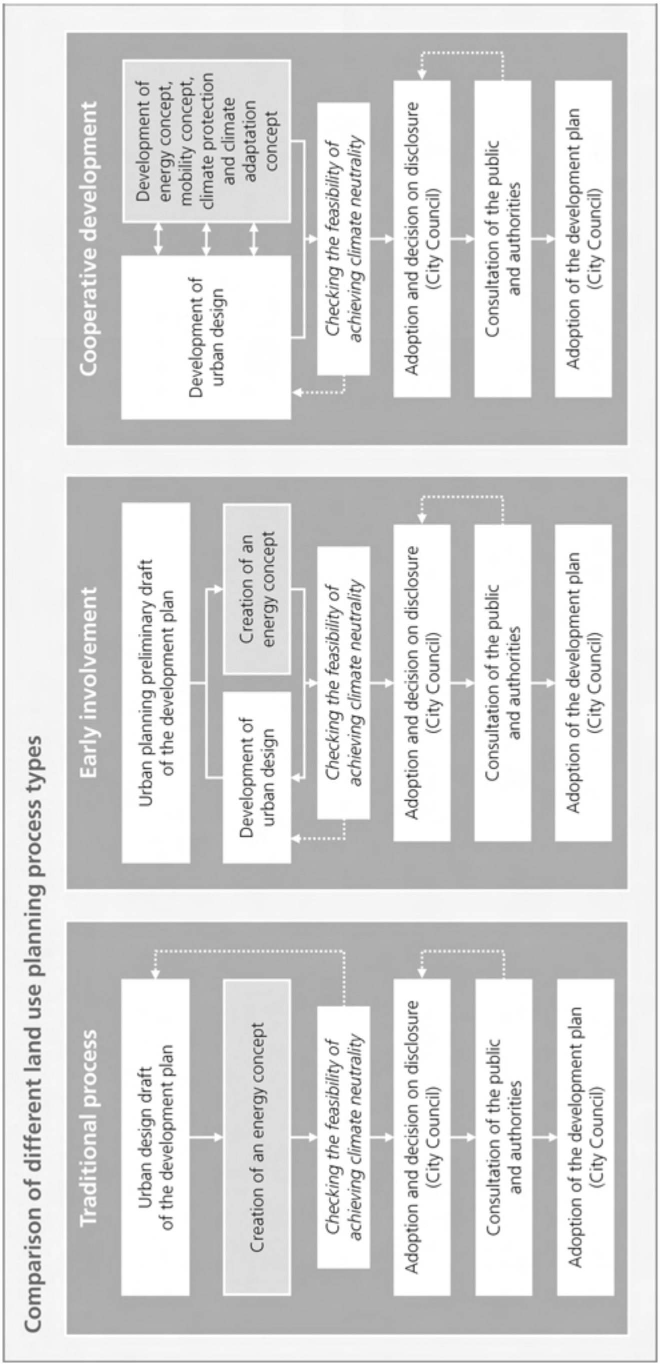

Figure 16.7: Different ways of integrating the energy concept into the development of the land use plan.

2. Cooperative development of the land use plan

The urban planning department, which leads the land use planning process, should organise it in a more cooperative way. For example, urban planning concepts can be developed jointly in workshops with experts for energy, mobility, climate protection and climate adaptation solutions, thus integrating their competences in a co-creation process from the very beginning.

3. Verification of the development plan to achieve climate neutrality

Draft development plans should be checked to see whether they are capable of achieving climate neutrality before they are submitted to the municipal council for a decision. The criteria for the assessment should be defined at the beginning of the planning process. If the criteria are not met, the design should be revised.

4. Preparation of a climate report as an annex to the development plan

Due to the comprehensive importance of climate protection, a report should document which measures of the development plan will protect the climate, which measures will be taken for climate adaptation and to what extent the preconditions for achieving climate neutrality in the district will be created.

5. Targeted communication on conflicting goals and stakeholder involvement

The more complex the target system, the more conflicts of objectives can develop. In order to resolve the conflicts as consensually as possible, on the one hand the conflicting goals, their causes and the respective implications of the solution approaches should be worked out and presented, and on the other hand the interested and affected stakeholders should be involved in the discussion and solution finding.

In order to support the municipalities in the preparation of climate-neutral land use plans, the following measures should be taken at federal or state level:

6. Further development of urban land use planning in the Building Code with a focus on climate protection

Climate protection and climate adaptation should be strengthened as priority objectives in the requirements for urban land use planning in the Building Code (BauGB), and the climate neutrality necessary for this should be established as a goal. The evaluation of the measures to achieve the objectives should be specified by an audit and reporting obligation. Furthermore, the introduction of cooperative methods of urban land use planning should be facilitated.

7. Support for the development of climate-neutral land use plans
The municipalities need support in the preparation of climate-neutral development plans, e.g. by providing a guideline for the procedure and organisation of the processes, a template for the model of a climate-neutral neighbourhood, a set of criteria for checking climate neutrality and other climate-relevant aspects, as well as text modules for the inclusion of climate protection measures in the textual stipulation or justification of the development plan. Furthermore, methods for enhanced public participation and the resolution of conflicting goals should be developed and conveyed in order to do justice to the increased complexity of climate-neutral development plans.

The aim of the EnStadt:Pfaff research project is to transfer the findings to the development processes of other neighbourhoods in Kaiserslautern and in other cities in Germany. In Kaiserslautern, concrete results can already be recorded in this regard. For example, the city council has decided that "in all future land use plan and land use plan amendment procedures, the binding stipulation option of photovoltaic systems should be examined and the stipulation of the solar obligation should be applied as a matter of priority – with the greatest possible reduction of exceptional circumstances" (Stadt Kaiserslautern 2021a). With regard to the urban land use planning processes, it can be assumed that the closer cooperation now practised between urban planning, the environmental department, the utilities and other stakeholders involved will also lead to earlier and closer coordination in future neighbourhood development projects. However, a formalisation of changes in the processes has not yet been undertaken.

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Patrick Huwig, Thomas Anton

17 Methods for the Development of Energy Concepts for Climate Neutral Neighbourhoods

Summary: The development of climate-neutral neighborhoods requires integrated planning from the outset, as well as early consideration of possible influencing factors from the various sectors (especially electricity and heat supply, mobility, wastewater and waste disposal). Already in the course of an initial framework plan design, fundamental decisions should be made as to the objectives with which the neighborhood is to be developed. If a holistic approach is taken across all sectors, appropriate precautions should already be taken in the framework planning, since many measures require public areas. These include, for example, heating centers, mobility stations, and the necessary transformer stations, of which several may be required in a densely built urban neighborhood with heat pump supply and many e-charging stations. Accordingly, it is also advisable to involve relevant stakeholders at an early stage so that all objectives, obstacles and conflicting concerns can be taken into account from the outset. Regular monitoring is recommended in order to check the achievement of objectives and to be able to control them if necessary. If necessary, this can provide an answer to how the share of renewable energy supply in the neighborhood develops, to what extent greenhouse gas emissions are reduced in the course of establishing a sustainable energy supply, and whether the goal of climate neutrality can be achieved and ensured in the long term.

17.1 Background and Challenges

The climate-neutral supply of urban neighbourhoods with locally available resources is associated with numerous challenges and compromises between the various stakeholders involved in planning process. Dense and multi-story developments, electricity/heat-intensive types of use (commercial, retail, service), the supply of new buildings and existing buildings (possibly with monument protection) lead to the fact that high energy requirements must be met on relatively little available supply area for renewable energies (in particular limited available roof areas, roof areas for solar energy use, see Figure 17.1).

In addition, there are various competing situations and conflicting goals that require a compromise to be found, with the participation of all relevant actors and decision-makers:

Patrick Huwig, **Thomas Anton**, Trier University of Applied Sciences, Environmental Campus, IfaS Institute, Germany

https://doi.org/10.1515/9783110777567-017

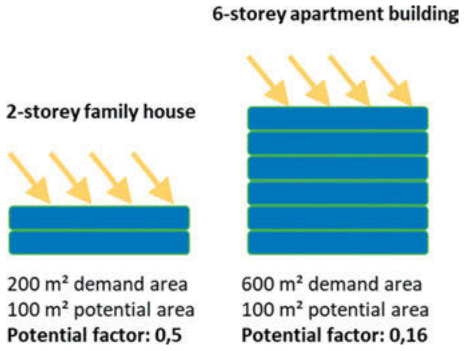

Figure 17.1: Premise of dense multi-story development in the urban area (high demand, limited space for solar energy).

– Area competition (roof areas): In urban areas, it is often imperative that roof areas fulfil several tasks. On the one hand, retention areas are needed to mitigate / buffer heavy rainfall events and allow as much rainwater as possible to infiltrate into the neighbourhoods. At the same time, the roof areas are needed in terms of energy supply for the generation of solar power (PV) and / or solar heat (ST). The architects and marketers are also pursuing the goal of generating as much sales revenue as possible, which is why as much saleable usable space as possible is being created, which at the same time should be as aesthetically pleasing and appealing as possible. In particular, staggered floors and roof terraces are therefore part of everyday practice in many urban development framework plans, which limit the potential areas for retention areas and solar energy use.
– Efficiency standard / minimize energy consumption: An important starting point for the realization of climate-neutral neighbourhoods is first of all the minimization of energy demand. Since the potential areas available in urban areas are very limited and subject to competing uses (limited production surface), it is all the more important to make the consumption side as efficient as possible. In this respect, it is possible, for example, to oblige investors to comply with higher building efficiency standards (e.g., passive house) in order to be able to supply the efficient buildings with higher shares of the limited available potential areas for energy generation. A frequently used argument by land marketers is that such requirements will deter potential investors and make the land more difficult to market. However, practice shows in many cases that nowadays many investors are willing to provide more than is required by law. Another starting point for minimizing the requirements already lies in the urban development framework planning. In addition to the optimal orientation of buildings (roof surfaces, main facades facing south), the AV ratio of buildings in particular has a major influence on the subsequent energy consumption of the neighbourhood. For example, the heat demand of buildings with a high AV ratio (e.g., 0.8 to 1.0) can be about 20 to 30% higher than that of compact buildings with a low AV ratio (e.g., 0.3 to 0.4) From an energy perspective, it is therefore advisable to realize buildings that are

as compact as possible in order to ensure low transmission heat losses. From the point of view of architects and marketers, however, this often conflicts with architecturally high-quality neighbourhoods with a high quality of stay, which is why many framework and development plans feature nested / smaller-scale buildings and building complexes.

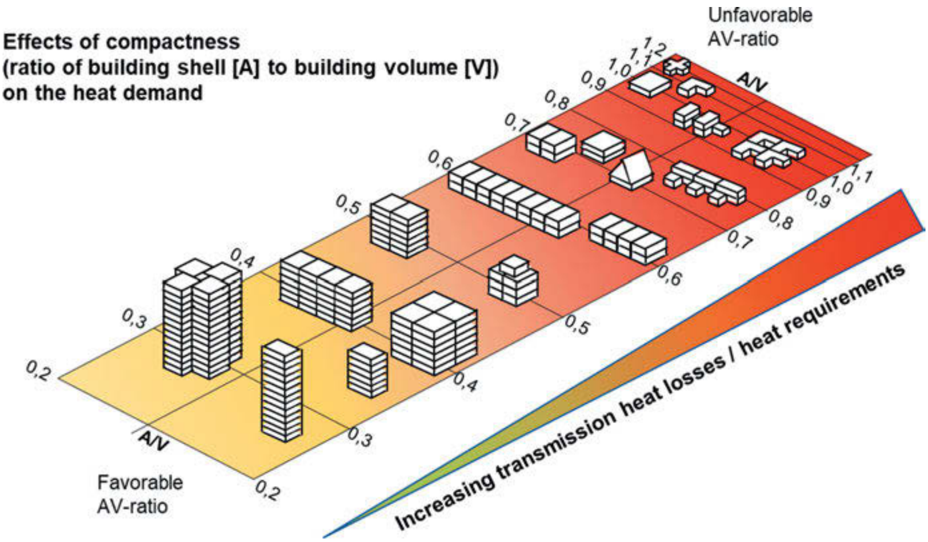

Figure 17.2: Effects of building compactness (AV-ratio).
(Own representation based on (Wirtschaftsministerium Baden-Württemberg 1998))

17.2 Early Influence on Framework and Development Planning

If the entire planning process is considered, numerous additional aspects arise beyond the influencing factors already listed above that must be thought about together from the beginning in order to ultimately obtain a framework plan / development plan that is acceptable to all actors and stakeholders. These include quality of stay and aesthetics, as much marketable space as possible, building efficiency standards, PV and ST areas for energy generation, retention areas, noise protection, microclimate, roof gardens and roof terraces, recreation/retreat spaces, mobility, supply and disposal, and social aspects (affordable housing, accessibility).

Practical experience shows that municipalities often have urban framework plans developed without taking into account the most important aspects of innovative and climate-neutral neighbourhood planning. Practical experience also shows that once plans have been drawn up, they are rarely deviated from, and fundamental changes are often no longer possible or desired, since a great deal of time and money has already gone into preparing the drafts. However, especially the energy aspects (compact building structures, orientation of the main facades and roof surfaces), but also influencing factors that affect the mobility sector as well as the supply and disposal structures (including mobility stations and waste collection points in the public space) are important factors that should be included in the first draft version of a framework planning.

The early involvement of all relevant stakeholders as well as the identification of conflicting goals or competing situations that require compromise should therefore be included in the first draft of a framework plan.

A mission statement can help to capture the goals for the neighbourhood / project in order to concretize them in the next step and to be able to derive the associated requirements for framework planning, time planning and infrastructure planning. The interests, goals and requirements of all relevant actors and stakeholders should be included in the mission statement so that conflicting aspects can also be identified at an early stage and appropriate compromises can be found (see also anthology Topic 1 – Mission Statement).

A selection of common stakeholders whose goals and interests should be taken into account at an early stage can be found in the following list, which may need to be expanded depending on the scope of the project and the topics to be addressed:

- Municipal actors: urban planning department (buildings, public space, traffic areas), urban drainage (pipeline planning, retention areas, green roofs), public utilities (pipeline planning, transformer stations in the neighbourhood), climate protection department (municipal climate protection master plans and objectives), approval authorities
- Political actors: City council, depending on the size of the project, possibly also district or state politics (decision-making on objectives)
- If necessary, land owners, investors, citizens' organizations
- Consulting / accompanying institutions on various specialized topics:
  - Architecture, spatial planning (solar urban land use planning, microclimate)
  - climate-neutral energy supply (high efficiency standard, location of heating centre, type of supply, media lines, solar obligation)
  - Waste collection/disposal (e.g., combined pick-up and drop-off systems, upcycling centre, repair café, swap meet, lending workshop)
  - Wastewater management (stormwater/service water management, retention areas in combination with biotopes, greywater/blackwater separation)
  - modern mobility offers (planning of mobility stations in public areas)
  - Environmental impact (CO_2 balancing, grey energy, ecological footprint, ecological building materials)
  - Social aspects (livability / comfort in the neighbourhood, accessibility, multigenerational concepts, community promotion, promotion of regional products, urban gardens / urban gardening)
  - Biodiversity (multifunctional greening, nesting aids, insect hotels)

In the course of integrated planning, it is important to record the respective interests and the associated requirements, since many of the listed topics can have an influence on spatial planning – especially the provision of public areas in framework planning. Concrete examples for the provision of public areas / municipal buildings in the framework planning are, for example:

- A high degree of electromobility and heat pumps may lead to several transformers in the neighbourhood, which have to be planned accordingly
- Depending on the energy concept, the framework plan may require the location of various technical areas (e.g., heating centre, heat storage, geothermal drilling field, solar systems in public spaces)
- Public mobility stations for the reduction of individual traffic require corresponding municipal areas
- The establishment of circular economy models such as a repair café, upcycling centre, lending workshop, swap meet, regional goods store, etc. also require the provision of municipal land or buildings.

One example of conflicting goals and the resulting competition for space is the fact that as many solar systems as possible should be installed to achieve energy goals, and thus the roof areas should be used primarily for energy production (electricity and / or heat). On the other hand, especially in urban areas, sufficient retention areas usually have to be created; moreover, in view of rising temperatures, the microclimate in the neighborhood should not be neglected. Biodiversity aspects to promote biodiversity in urban areas are also increasingly being incorporated into urban planning. In densely built-up neighbourhoods, this means that roof surfaces in particular must be increasingly used for different functions (multifunctional roof surfaces). As part of EnStadt:Pfaff, in the course of reaching a compromise, PV green roofs were made mandatory within the framework of a solar statute, enabling solar power to be used (albeit to a somewhat lesser extent than with pure PV roofs), sufficient retention areas to be provided, the microclimate to be improved, and biodiversity to be promoted in the urban area (see also solar statute and design manual for the Pfaff site in Kaiserslautern).

17.3 Energy Demand and Potential Analyses

The energy demand analysis is usually based on the area balance of an urban planning framework or a development plan and has the task of projecting the future demand (MWh) for electricity, heating, hot water and, if necessary, cooling energy as well as energy for mobility purposes. Ideally, the outline planning has already been developed, or at least optimised, with regard to energy production and savings (orientation of facades and roof surfaces, compact building structures, high efficiency standards of the buildings). Depending on the objective or scope of the issues considered, other needs can also be recorded, such as domestic water needs (to develop grey water concepts) or electromobility needs (number of charging points and electricity consumption). The requirements for new buildings can be estimated using a characteristic value procedure; alternatively, software simulations can be created for representative reference buildings, the results of which subsequently provide the characteristic values for other buildings. The different types of use (residential, commercial, retail, service, etc.) must be taken into account, for which corresponding sector-specific and characteristic values can be used. If existing buildings are included, the consumption data of the past years can be used for this purpose, if necessary, with consideration of upcoming energy refurbishment measures. If these are not available, a software simulation can be used as described above.

Once future consumption patterns have been forecasted, the potential analysis can answer the question of how much of the required energy can be covered by local sources. The potential analysis should include all available resources, such as photovoltaics and solar thermal energy, geothermal energy (geothermal probes, surface collectors), wastewater heat utilization, commercial/industrial waste heat from the immediate vicinity. If the neighbourhood is located on the outskirts of the city, wind turbines or ground-mounted PV systems can be included in the planning if necessary. If there are flowing waters in the vicinity, the hydropower potentials could also be surveyed. Particularly in urban areas, the use of biomass is often ruled out due to fine dust emissions, which should be checked accordingly in advance. In the field of geothermal energy, the geoportals of cities and federal states often help to determine the general suitability of the area.

Once the demand and potential analyses are available, a comparison of the demand and potential structures makes it possible to derive various supply options (variants), which can then be examined in more detail from a technical, economic and ecological perspective.

Figure 17.3 shows the electricity demand and the PV electricity generation potential for each of the 9 construction fields of the Pfaff neighbourhood. As can be seen, none of the building sites is able to produce enough electricity to cover the entire electricity demand, which is due to the multi-story construction with some electricity-intensive types of use (commercial, trading, service). Depending on the boundary of consideration, the coverage rates are around 65% in relation to the use-related electricity demand (households, commercial) and around 35 to 40% in relation to the total electricity demand (incl. electric mobility and cooling supply).

With the help of so called “customer plants” (which allow electricity exchange from one building site to the another)” and intelligent energy management systems, the real time surpluses and deficits are to be balanced out so that as much PV electricity as possible can be generated and consumed within the neighbourhood.

17.4 Development of Supply Variants

Based on the demand and potential analyses, the technical supply variants can be created and coordinated with the relevant decision-makers. Depending on the variant, certain legal requirements must be considered in advance and discussions with the relevant authorities and agencies are necessary, for example regarding the use of wastewater heat or geothermal use on a larger scale. Particularly when using geothermal probes on conversion sites, attention must be paid to possible problems with contaminated sites, which often precludes the use of geothermal probes or at least makes it more difficult.

For centralized, grid-connected variants (heat grids), there must be a consensus in the planning team regarding the establishment of possible connection and usage constraints, since the economic viability of heat grids is strongly dependent on the number of connected buildings. For decentralized variants (e.g. heat pumps for water heating in each building), it may also be necessary to define certain systems in a binding manner here as well, which can usually be defined as part of the purchase agreements or urban development / private law contracts. This is particularly necessary for innovative concepts (smart grids / virtual power plants), in which all systems (generators, storage and consumers) must be coordinated and have to communicate with each other. The communication of the plants with each other makes it possible to exchange the generated energy within a neighbourhood across properties in order to enable the highest possible self-consumption and autarky rates or the maximum utilization of local resources. In this context, one speaks of sector coupling, in which, for example, solar energy is used for stationary electricity applications, for mobility purposes or for heat generation (heat pump).

A suitable technical concept must be developed for each of the possible study variants (system dimensions, system drawing) and these must be compared economically (total annual costs or heat prices). The recommended calculation method used in Germany is the VDI 2067 (economic efficiency of technical building systems), which depicts a full cost calculation. When comparing different supply variants, it is important to include all cost items, since the investments in themselves do not provide any information about the long-term economic efficiency of a variant. For example, systems using fossil fuels are generally very cheap to purchase, but the running costs (mostly fuel) are often higher than for systems based on renewable energies.

Full cost accounting includes both, capital expenditures (in the form of annual payments), as well as all ongoing costs required to operate the plant:

- Cost of capital, discounted investment as annual annuity (credit)
- Consumption costs, costs for energy sources and auxiliary energy
- Operating costs, maintenance and repair costs
- Other costs, including costs for insurance and administration

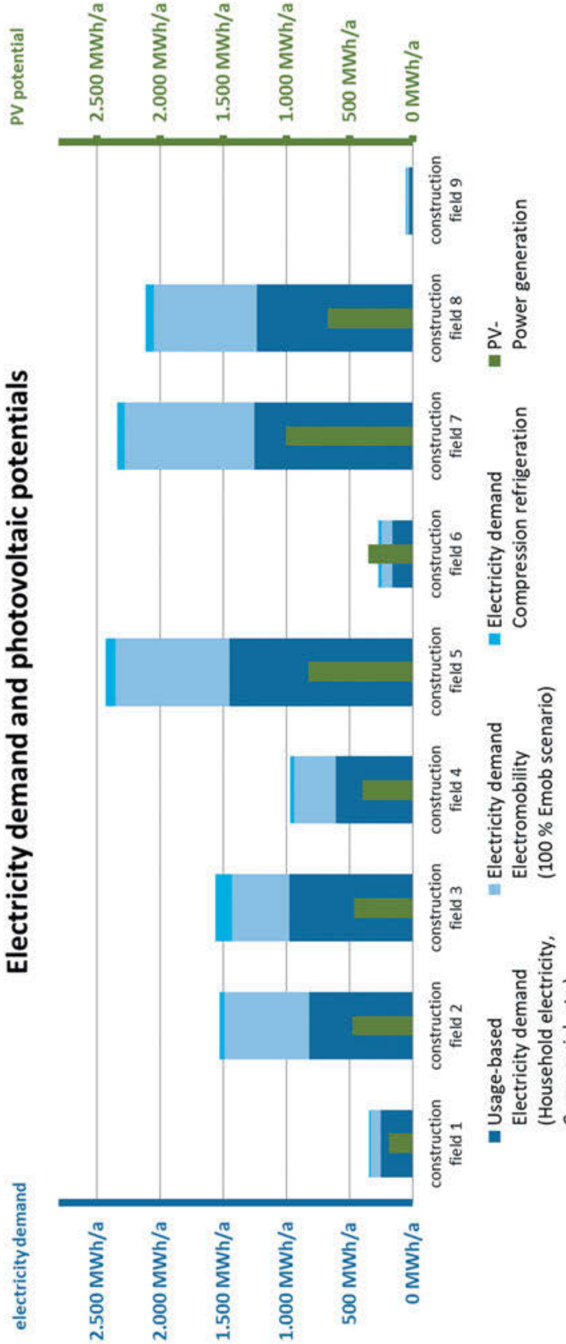

Figure 17.3: Power requirements and PV power generation per construction field.

As a result, the total annual costs for each variant investigated are available, from which, for example, a predicted heat price can be calculated.

In the case of plants using renewable energies, the investments and the resulting capital costs in particular represent the largest cost block. In the case of fossil-fuelled plants, the largest cost block is usually the consumption costs (e.g. for natural gas, heating oil), as the plant technology can usually be obtained at low cost. It is therefore advisable to also take into account the price increases for the energy sources, as there is a corresponding leverage effect here, in which the RE plants can play out their advantages (in particular price stability) in the long term.

In addition to the economic criteria, it is nowadays a “must” to survey the ecological impact, which can be done by calculating the primary energy requirements and the corresponding CO_2 equivalents of the energy sources used.

The results of the work enable a preliminary selection of suitable variants for supplying the neighbourhood and finally a decision on a variant to be favoured. A detailed planning feasibility study must then be prepared or commissioned for this variant. In contrast to the concept phase, in which construction cost tables, characteristic values and empirical values are used, the feasibility study must then concretize the preliminary investigation. Here, the focus is on concrete indicative price offers for the plant technology, the performance management is coordinated with the responsible trades, the location for the heating centre or heat transfer is determined, and initial price negotiations are conducted with, for example, municipal utilities or other energy suppliers in order to concretize the prices for any additional energy sources that may be required (labour and basic/service prices).

As part of the EnStadt:Pfaff project, various supply options were investigated, such as wastewater heat utilization, use of industrial waste heat, air-source heat pumps and solar thermal energy with seasonal heat storage. For economic reasons, a heat supply based on a connection to the existing district heating system of the City of Kaiserslautern was ultimately decided upon. Since Stadtwerke Kaiserslautern is striving to make the district heating supply in the city climate-neutral, it can be assumed that the heat supply in the neighbourhood can also be climate-neutral in the future. PV systems that optimize the cross-building energy exchange in the neighbourhood via customer systems and are coupled to the hot water supply (for reheating) and the electromobility infrastructure (100% e-mobility as a goal) round out the concept (sector coupling).

17.5 Conclusion and Recommendations

When developing climate-neutral neighbourhoods, it is essential to consider the energy aspects of district planning from the very beginning. Ideally, the energy aspects should already be included in the first draft version of an urban planning framework, since the course for the future orientation of the neighbourhood is already set here. As shown in the course of the paper, it is even advisable to record all interests and concerns beyond the energy aspects at an early stage in order to be able to take into account the effects and interactions with each other (competitive situations) as well as the effects on the framework planning (in particular the provision of public space) at an early stage. This saves time and money, as ideally the planning does not have to be adjusted several times. At the start of the EnStadt:Pfaff project, an urban planning framework was already available, which had to be adapted and updated for a total of four times during the course of the project, since many relevant topics and influencing factors could only be determined and elaborated gradually.

Particularly, with regard to the energy aspects, it can often be observed that the necessary willingness to take risks and break new ground, as well as the necessary decision-making (resolutions), e.g., for or against certain energy supply variants, are lacking or delayed for a long time. Here, the participation of decision-makers (e.g., mayor, lord mayor, city council) is required to drive the project forward and to accompany and force its implementation. In addition, continuous involvement of and consultation with higher-level bodies (e.g., city or municipal councils) is required to secure the decision-making processes.

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Sara Schierz, Manuel Schaubt

18 Greenhousegas Balancing and Life Cycle Analysis in the Context of Climate-Neutral Neighbourhoods

Summary: The EnStadt:Pfaff project is a project area for an exemplary neighbourhood development with ambitious goals for energy-efficient renovation and the expansion of renewable energies. In order to achieve the goal of climate neutrality at the neighbourhood level, far-reaching and interconnected strategies are required so that a transformation can succeed in terms of climate protection and resource efficiency.

In order to evaluate the climate impact the EnStadt:Pfaff project, the energy and greenhouse gas balance is presented as a monitoring instrument in the following article. In addition to an assessment of the climate protection effect in the transformation path of the neighbourhood, the importance of the raw materials and materials used in construction is also classified in the context of resource efficiency.

18.1 Classification of Climate Neutrality at the Neighbourhood level

At the present time, climate protection and resource conservation are social tasks that can only be mastered through the involvement and cooperation of all actors from politics, administration, society, business and science. The urgent need for action is made clear by, among other things, stricter legal and political framework conditions. For example, in the course of the German government's Climate Protection Act 2021, the nationally agreed targets for reducing greenhouse gas emissions compared with the base year 1990 were raised significantly and the goal of climate neutrality for Germany by 2045 was established.[1] In addition, the ambitious savings targets in terms of climate protection and resource efficiency are not only reflected in the Building Energy Act (GEG), which replaced the EnEV, the EEWärmeG and the EnEG and came into force on November 1, 2020, but are also expressed in the recent amendment of the EU Buildings Directive and the "Fit for 55" package of measures (reduction of net greenhouse gas emissions by 55% by 2030 compared with 1990) to implement the European Green

1 Federal Climate Protection Act of December 12, 2019 (BGBl. I p. 2513), as amended by Article 1 of the Act of August 18, 2021 (BGBl. I p. 3905), §3 para. 1.

Sara Schierz, **Manuel Schaubt**, Hochschule Trier, Umwelt-Campus, IfaS, Germany

https://doi.org/10.1515/9783110777567-018

Deal. In this context, other environmental indicators and resource parameters are increasingly coming into focus in addition to energy consumption and greenhouse gas emissions. Consequently, contributions to climate and resource protection must be made in all areas of society and a transformation path must be considered holistically.

Against this background, neighbourhoods are promising areas of action for implementing climate protection and resource conservation. This is because they not only offer the opportunity to develop concepts that enable a climate-friendly energy supply and an environmentally friendly mobility offer. The individual elements can also be meaningfully linked with one another in the sense of a functioning sector coupling, as the preceding results of the neighbourhood energy and mobility concept show.

With the overarching goal of implementing a climate-neutral residential, commercial and technology quarter on the Pfaff site in Kaiserslautern, the abandonment of fossil energies is indispensable in all areas, both from a climate protection and a resource protection perspective. In addition to the investment cycles and expansion or renewal rates of the specific technologies and measures in the individual applications, the climate protection effect in the transformation path is particularly relevant in this respect. It becomes clear that energy, heat and transport transformation must be thought of together. In addition, efficient and long-term use of raw materials in economic cycles with the lowest possible impact on the environment is required in order to achieve the goal of climate neutrality in the final expansion in 2040.

In the context of resource efficiency, the raw materials and materials used in construction, among other things, are increasingly coming to the fore. This essentially involves the grey energy bound up in the building materials and construction materials and the associated environmental impact and emissions. This can be represented by the parameters Cumulative Energy Expenditure (CED) and Cumulative Energy Consumption (CEC), subdivided into renewable and non-renewable or as primary energy as Renewable Total (PERT), Non-Renewable Total (PENRT), Renewable Material (PERM) and Non-Renewable Material (PENRM).

As the efficiency of buildings increases due to the additional use of materials and technical building equipment (TGA), the proportion of energy used along the value chain of building construction and the associated emissions continue to rise, so that a holistic approach to buildings, from the production of building materials, through the construction of buildings, their operation, to demolition and the subsequent recycling of materials, appears to make more and more sense. It can therefore be assumed that the consideration of building use within the framework of a life cycle analysis or life cycle assessment could also become binding as an EU requirement in the future.

In the present context,[2] climate neutrality refers to "net zero" of the relevant greenhouse gases (CO_2, CH_4 and N_2O) as defined by the German government in the 2021 Fed-

2 Federal Climate Protection Act of December 12, 2019 (BGBl. I p. 2513), as amended by Article 1 of the Act of August 18, 2021 (BGBl. I p. 3905), §3 para. 2.

eral Climate Protection Act (Bundesklimaschutzgesetz 2021). This can be applied to both energy and non-energy emissions, depending on the defined scope of the balance and the areas considered. It means that all GHG emissions should be reduced as much as possible, while GHG emissions that cannot be avoided can be offset by natural and technical GHG sinks. Any offsetting of emissions should be limited to certified GHG removal methods only, to provide certainty that the carbon is permanently sequestered.

18.2 The Greenhousegas Balance of the neighbourhood

In order to be able to quantify and classify the goal of climate neutrality for the Pfaff Quarter under consideration, an energy and greenhouse gas balance sheet was drawn up as a monitoring tool within the framework of a holistic consideration of the future neighbourhood energy supply. The basic parameters of an energy and GHG balance are the system boundaries, the period under consideration, the selected balancing method, and the definition of the scope of the balance.

System boundary: In this analysis, the Pfaff quarter with all existing and new buildings corresponds to the balance boundary.

Period under consideration: The energy flows are considered and evaluated on the basis of the annual requirements determined for the final development of the district. The final development is defined as the target year 2040.

Accounting method: The greenhouse gas balance was drawn up using the methodology of a final energy-based territorial balance based on the recommendations of the practical guide “Klimaschutz in Kommunen” (Climate Protection in Municipalities), published by the German Institute of Urban Affairs.[3]

Balance scope: Defining the balance scope for a neighbourhood is complex and requires decisions on what is included. In the present energy and GHG balance, the required final energy was determined on the basis of the useful energy requirements based on the neighbourhood energy concept, and the different energy sources for the consumer groups specified by the development plan – residential, office / services, commercial, parking and mobility – were recorded. The upstream chains of the final energy demand are to be taken into account within the framework of the applied balancing method (end-energy-based territorial balance). For this reason, after the final energy demand was recorded, the GHG emissions were calculated, broken down by energy source, and the primary energy input required for this was balanced. Different

3 German Institute of Urban Affairs gGmbH (2018), p. 197.

climate impacts are associated with the final energy demand of all consumer groups considered, which are presented below using the GHG emissions indicator. The sum of the GHG emissions caused according to the users considered always depends on the energy sources used, since each energy source has a different emission intensity.

The forecast of final energy requirements (electricity, heating, cooling, mobility) concludes that around 19,000 MWh will be needed in the final development of the neighbourhood. This results in direct GHG emissions that are attributed to the neighbourhood. This includes all GHG emissions from the energetic use of fossil and renewable energy sources, taking into account the specific electricity, fuel and fuel requirements of the considered users residential, office / service, commercial, parking, mobility and compression cooling. Within the system boundaries, not only the building operation is evaluated in a further step, but also the construction as well as the disposal of the buildings are taken into account in the balance as "grey energy".

Applying the end-energy-based territorial principle, the question now arises here of the thg-side evaluation of the electricity mix. In accordance with the recommendations from the practical guide "Klimaschutz in Kommunen" (Difu),[4] the emissions in the electricity sector are calculated in a first step using the federal electricity mix. In addition, a comparison is made with the regional electricity mix to illustrate the climate protection effect of expanding local renewable electricity generation facilities. If local electricity generation does not cover the entire electricity demand of the neighbourhood, the remaining electricity demand is calculated using the federal electricity mix.

Figure 18.1 shows the projected GHG emissions of the Pfaff Quarter in the final development in 2040, taking into account the federal electricity mix (Territorial Balance BUND) and in comparison with the regional electricity mix (Territorial Balance REGIO), which includes the full development of the PV potential on the site. Also taken into account the GHG emissions of grey energy from new construction and renovation of the buildings in the neighbourhood.

In the final development of the neighbourhood, annual greenhouse gas emissions of approx. 746 t CO_2 e are generated at this time, taking into account the federal electricity mix (territorial balance BUND), which are mainly caused by the grey energy, if conventional buildings materials will be used (wooden buildings for example could lower the impact). This is due to the fact that the high efficiency standards set mean that, in relative terms, the CO_2 of the materials used in the final construction have a significant share. From a climate protection perspective, the next step is to evaluate the GHG emissions in the electricity sector, taking into account the local electricity mix, which considers the development of all available PV potentials and thus a rapid substitution of fossil electricity generation and use in the neighbourhood (territorial

4 German Institute of Urban Affairs gGmbH (2018), p. 200.

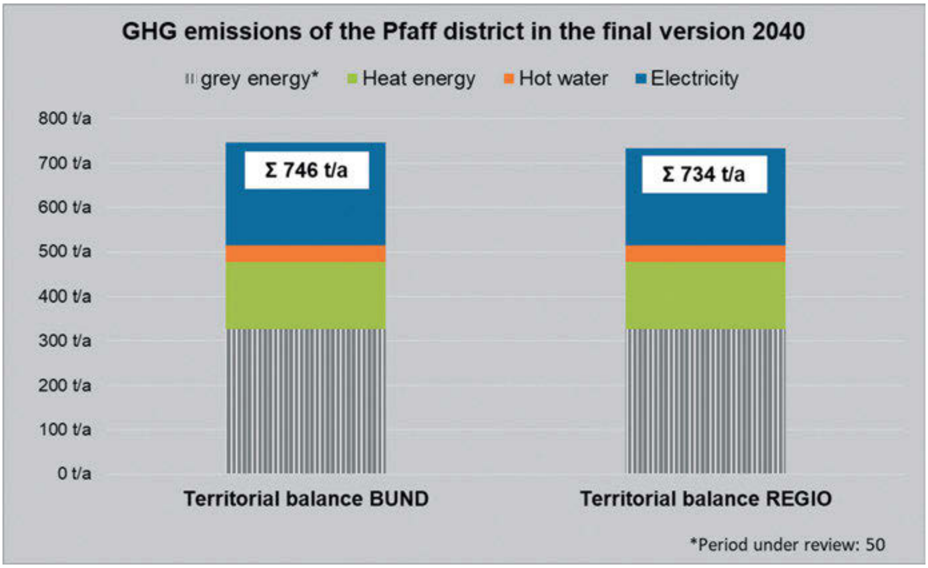

Figure 18.1: GHG emissions of the Pfaff quarter in the final version 2040.

balance REGIO). The development of the available PV potentials in the neighbourhood is sufficient to cover about 38% of the final electricity demand via PV. The GHG savings through the development of all PV potentials in the neighbourhood amounts to about 12 t CO_2 e in 2040, so that the remaining total emissions of the considered neighborhood decrease to about 734 t CO_2 e.

It becomes clear that grey energy causes most of the GHG emissions in the final development of the neighbourhood. With a view to achieving the goal of climate neutrality, it becomes clear that in the future, products and materials should be considered in the context of the renovation and new construction of buildings that have a low environmental impact and were increasingly manufactured using renewable raw materials and regenerative energies. The energy-related GHG emissions in the neighbourhood, on the other hand, are influenced by two aspects. Firstly, the share of renewable energies in the supply of electricity, fuel and heating fuel, as well as the demand for the specific energy sources in each case. It should be noted that the PE factors or CO_2 equivalents will behave dynamically in the coming years due to the decarbonization of the supply systems, i.e., they will continue to decrease over time.

The final development of the neighbourhood in 2040 already takes into account the possible reductions through efficiency improvements as well as the avoidance of and shift to electricity-based, efficient technologies in all application areas. The results show that although the national power plant fleet for power generation and the district heating supply will have been largely converted to renewable energies by this time, around 734 t CO_2 e will still remain in the neighbourhood each year. This is due to greenhouse gas emissions in the upstream chains of the specific energy sources that will still remain in the system in 2040. As an example, the German electricity mix can be mentioned here. Current studies conclude that 100% renewable electricity generation in Germany can be achieved in the next 10–15 years with ambitious efforts.[5] However, regenerative power generation is associated with a small proportion of GHG emissions. Within the framework of a holistic view, regarding the life cycle assessment of the individual energy generation plants, these are mainly due to the construction, the fuel supply or the transport.

As the final development of the neighbourhood will be completed in 2040, GHG emissions have to be compensated by additional local measures in order to achieve and ensure climate neutrality (net zero). To compensate for the remaining GHG emissions, for example an open space PV system of around 37 MW would be required.

18.3 Consideration of Grey Energy and Associated Environmental Impacts in the Neighborhood

In addition to energy consumption and GHG emissions from building use (heating/ cooling, hot water and electricity), the resources consumed in construction are also increasingly coming to the fore. These are essentially the grey energy bound up in building materials and construction materials and the associated environmental impacts and emissions. There is a wide range of parameters in the field of life cycle assessment (LCA) according to DIN EN ISO 14040.

Figure 18.2 illustrates this with a representation of the ReCiPe method, which was developed in the Netherlands in collaboration between the Rijksinstituut voor Volksgezondheid en Milieu (Dutch Public Health and Environmental Protection Agency), Radboud University in Nijmegen, the Institute of Environmental Sciences CML in Leiden, and the company PRé Sustainability from Amersfoort.

The figure shows an example of the step-by-step transfer of a large number of emissions and related parameters and associated indicators into the three more easily understandable categories of human health, ecosystems/biodiversity and resource costs. At the end, the possibility of merging into a single “score” is envisaged, although this last step – due to the necessary weighting of the categories – is to be evaluated quite subjectively and may therefore lead to different results individually.[6]

In order to avoid an overload of indicators in the result, only a manageable selection of environmental impacts was adopted for the EnStadt:Pfaff project. In total, two energy indicators are mapped in each case (CED renewable, CED non-renewable, CEC

5 DIW Berlin – German Institute for Economic Research e. V (2021), pp. 507–513.
6 Goedkoop/ Heijungs/ Huijbregts et al. (2013), p. 3.

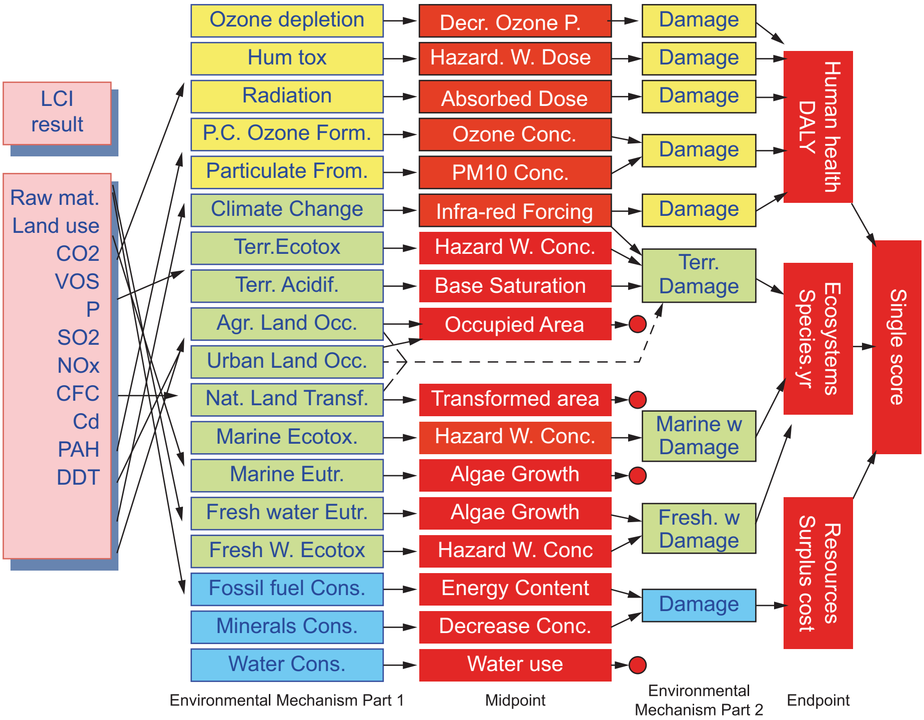

Figure 18.2: Relationship between "LCI parameter" (left), "midpoint indicator" (center) and "endpoint indicator" (right) in ReCiPe 2008.

renewable, CEC non-renewable) and five environmental indicators (GWP, AP, EP, ODP, POCP) according to the Sustainable Building Assessment System (BNB).

The selected environmental indicators are based on the one hand on the popularity or awareness of the corresponding environmental impact, but on the other hand also on the pure availability of data on products and materials. Due to the popularity of climate-impacting gases, it seems consistent that the environmental impact of climate change is reflected in the results. This is presented in terms of GHG emissions in CO_2 e and is categorized as human health. Furthermore, the ground-level ozone creation potential in C_2H_2 e and the ozone depletion potential in CCl_3F e. are shown, which also both correspond to the human health category, as well as the acidification potential in SO_2 e and the eutrophication potential in PO_4 e for the ecosystems/biodiversity category. The resource costs category, on the other hand, is expressed by the two energy indicators and their subdivision into "renewable" and "non-renewable".

In order to consider the building sector more comprehensively in the future and to prefer building concepts with lower emissions and environmental impacts, which in the best case facilitate flexible reuse in the form of the reuse of components and materials or the recycling of materials, a systematic collection of this data and a uniform evaluation concept as the result of life cycle considerations are required. DIN EN ISO 14040 to 14044 describes the corresponding procedure. In addition, DIN EN 15804 already provides basic product category rules (PCR) regarding environmental declarations in the context of sustainability of construction works for construction products and construction services of all kinds.

In order to enable a target-oriented recording in this respect in the project, a database was created, which is essentially based on different versions of the Ökobaudat database and deals with the different materials used in the buildings of the quarter and their evaluation, in order to integrate corresponding aspects into the infrastructure and building planning and to enable an optimized deconstruction.

From today's point of view, the database Ökobaudat is to be regarded as the preferred suitable instrument in this respect due to its scope and orientation. It is based on the database for holistic balancing (GaBi). The database contains a number of 18 parameters describing resource use and other environmental information, as well as seven indicators of environmental impact, for each set of data provided on a construction product. These are presented along up to 17 sub-stages or life cycle modules according to DIN EN 15804. The presentation ranges from the production stage (A1 to A3) to the construction stage (A4 and A5), the use stage (B1 to B7), the disposal stage (C1 to C4) and credits and loads outside the system boundary (D).

Since only a few buildings in the neighbourhood have been the focus of renovation activities so far and the exact type and mass of the building materials used for this purpose could not be precisely traced so far, an extrapolation based on the planned total building stock was made for the consideration of the energy bound in the building physics. The content of the 8th AP interim report of AP 2.2.3 was mainly used to determine the existing building structures in the final construction. This is a life cycle assessment of the medical care center (MVZ). The "new construction" variant for the thermal building envelope examined in the report is decisive for the assessment presented here. Within the scope of the investigation, it was determined that the Global Warming Potential (GWP) emitted in connection with the variant "new building" is around 1,500 t CO_2 e for a building volume of approx. 68,200 m^3. If building components not taken into account here, such as the foundation, intermediate ceilings and interior walls, are included in the calculation by means of surcharges, this results in a GWP of around 1,750 t CO_2 e for the entire building.

By contrast, a building volume of around 640,000 m^3 can be determined for the Quarter in its fully developed state. If it is now assumed in a simplified manner that the other buildings in the Quarter are constructed and built in a similar way, this would result in around 16,500 t CO_2 e in connection with the production of the building materials used. In fact, the amount of emissions is likely to be even higher, as no other infrastructure or TGA has been considered for the time being. In addition, the other buildings also potentially have a lower ratio of gross volume to gross floor area on average, resulting in lower floor heights and thus higher material use per unit volume.

In the further course of the project, the exact recording of the building materials and construction materials used for the renovation activities at the MVZ according to types and quantities is planned, provided that data on this can be determined by the end of the project. In contrast to the previous observations, the building materials are not only to be represented as models, but are to be recorded and processed in detail according to individual products.

The data is recorded in the form of lists (life cycle inventory) and by assigning the exact individual product quantities to existing data records in the tool created for this purpose as part of the project. The units to be assigned to the respective building materials result from the data records and are therefore not freely selectable. This means that the required or used quantity may have to be entered in a different unit than intended.[7] In such a case, however, assistance is provided, if possible, by the following conversion of the entered quantity, as required, from mass to volume or vice versa. The representation supplements the entered value with the partial sentence “corresponds to x/y t/m^3”. This allows a quick comparison whether the intended quantity has really been entered.

Finally, the results derived from the entries (life cycle impact estimates) are recorded both in total and per unit of each selected material or building material for the parameters mentioned to describe resource use (CED renewable, CED non-renewable, CEC renewable, CEC non-renewable) and environmental impact indicators (GWP, AP, EP, ODP, POCP).

In addition to the total display, the Excel version of the tool also includes a level that places the quantities of energy and material emissions calculated for the parameters and indicators in a comparative context (life cycle assessment interpretation).

Regarding fossil energy or CED and CEC non-renewable, an equivalent in lignite is shown while for renewable energy or CED and CEC renewable, an equivalent in firewood is mentioned.

For the GWP, two references are made: firstly, the volume of air that would be polluted to such an extent that the permissible workplace limit value (AGW) according to the “Technical Rules for Hazardous Substances” (TRGS 900) of 9.1 mg/l would be exceeded[8] and secondly, the distance performance of a comparison vehicle (motor vehicle) that would emit the same emissions while covering the distance.

For the AP in SO_2 e and the POCP in C_2H_4 e the air volumes are also shown, which result at a MAK of 2.7 mg/m^3 and 11,500 mg/m^3, respectively.

For the ODP in CCl_3F e the area is shown for which the substance ozone is potentially completely decomposed up to a height of the air column of about 60 km. This is based on the fact that each molecule of CCl_3F e can deplete about 100,000 molecules of

7 Ex: You intend to enter a quantity of building material as mass in t, but the system specifies that the quantity for the selected building material is to be entered as volume in m^3.

8 Note: The 400 ppm of our atmosphere represent about 0.79 mg/l.

ozone before decaying and that there are about 6.42 g of ozone in a 60 km high air column of one m^2.[9]

Last but not least, a population equivalent (1.8 g/d total phosphorus) is listed for the EP in PO_4 e, which reflects the emission of phosphate as a service water load.

The procedure described here provides the owner of the MVZ with a detailed life cycle assessment of his building. This already fulfils the basic requirements for meeting the future specifications of the EU Building Efficiency Directive (EPBD),[10] according to which buildings in the EU with a usable floor space of more than 2,000 m^2 are expected to have to have a material passport from 2027.

18.4 Conclusions and Outlook

The required energy demand in the final development of the neighbourhood as well as the associated GHG emissions are mainly influenced by the available potentials of renewable energies, the energy import dependency as well as the resource use in terms of raw materials / building materials and land. In addition, the implementation of energy efficiency measures and demand reductions across all types of use considered makes a significant contribution to GHG reduction.

The results of the greenhouse gas balance of the neighbourhood have shown that a complete exploitation of all available potentials of renewable energies in the neighbourhood is not sufficient to achieve climate neutrality in the final expansion in 2040. Therefore, not only an ambitious approach to the expansion of renewable energies and the implementation of energy efficiency measures is required. In addition, further measures must be implemented, e.g. in cooperation with local actors, which additionally contribute to the climate neutrality of the neighbourhood. Regional climate protection projects that can be mentioned at this point include, for example, planting campaigns that are implemented in cooperation with the fruit and gardening association, educational institutions, associations or other actors. The planting campaigns aim at CO_2 storage through new plantings of trees, hedges, shrubs. Another possibility for an additional climate protection project is the application of bio char and the associated CO_2 storage in the soil, e.g. in cooperation with regional farmers. Likewise, additional climate protection projects for the expansion of RE outside the neighbourhood can be realized, e.g. in cooperation with a citizen's energy cooperative.

The described goal of climate neutrality is to be understood as an overriding objective, the achievement of which should by no means represent the end of climate

9 Cf. Öko-Recherche – Büro für Umweltforschung und Beratung (n.d.), Available at: https://www.oekorecherche.de/de/einleitung-die-ozonschicht (Accessed 28 March 2022).

10 Cf. EC (2022), Available at: https://ec.europa.eu/commission/presscorner/detail/en/QANDA_21_6686 (Accessed: 29 March 2022).

protection efforts. Rather, the achievement of the set targets is seen as motivation for further climate protection efforts. The achievement of these goals depends to a large extent on laws, regulations and guidelines issued by the EU, the federal and state governments, as well as future technologies and innovations.

Overall, it is clear that the transformation must go hand in hand in all areas under aspects of climate protection and resource conservation. The right balance must be struck between climate protection and resource conservation with regard to the rate of expansion, in order to minimize any peaks in raw material demand and cumulative greenhouse gas emissions, while at the same time providing the right incentives to ensure the long–term impact of measures and readiness for use of technologies as well as the infrastructures required for this purpose.

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Frank Elberzhager, Steffen Hupp, Svenja Polst, Phil Stüpfert,
Arne Surmann

19 A Climate-Neutral Smart City District Supported by Digital Solutions

Summary: The digital transformation is able to support a climate-neutral smart city district in various ways. We have focused on the users living in such a smart city district and have developed concepts and concrete solutions. In this chapter, we give an idea of the technical background and provide several examples from different domains, such as mobility, energy, and smart home. We discuss the challenges we encountered and how we solved them.

19.1 Introduction

The digital transformation and climate change are two of the greatest current megatrends. In the EnStadt:Pfaff research project, our main goal is to develop a climate-neutral smart city district. One question is how digitalization can support climate-friendly behavior in a smart city. To help answer this question, we have developed concepts and solutions to show how this can be implemented.

One basis for digital solutions are so-called digital ecosystems. From the technical point of view, such a digital ecosystem consists of a platform and various digital services. Different stakeholders participate in such an ecosystem by offering or consuming services. These services should support, for example, citizens in their climate-friendly behavior, for instance, by sharing information, but also by offering concrete apps that give hints on how to save energy. One important aspect in our project is our focus on the user perspective, i.e., we concentrate on and address real needs.

The question remains how the digital transformation can support climate neutrality in such a smart city district. In this chapter, we want to share some examples showing what solutions we have developed, but also what challenges we have faced.

Frank Elberzhager, **Steffen Hupp**, **Svenja Polst**, **Phil Stüpfert**, **Arne Surmann**, Fraunhofer Institute for Experimental Software Engineering IESE, Germany

https://doi.org/10.1515/9783110777567-019

19.2 Starting Situation and Main Challenges

In an early phase of the research project, we initially thought about what principles we wanted to follow when developing digital solutions. Our main driver was to be user-centric and future-oriented. In detail, we formulated the following guiding principles:

- The Pfaff district offers an excellently developed digital infrastructure for businesses, users, and residents in the district and is becoming an important building block of the "Herzlich-Digitale Stadt Kaiserslautern" initiative.
- The digital district platform unobtrusively supports quality of life and climate protection in the neighborhood. The platform offers services for many areas of daily life, such as energy, mobility, home, and community, which are interconnected.
- People's needs are at the heart of the digital platform, and all services and development activities are geared towards them. Citizens and users are actively involved in the development.
- The digital platform promotes the development of new services for the district and enables the linking of data from different services and external infrastructures. Through their interaction, innovative approaches to solutions for climate protection and a high quality of life in the district are created.
- The digital platform is open to participation by citizens and companies. It provides the technical and organizational framework for planning and developing, establishing, and deploying low-barrier digital services during development and after completion of the district.
- The digital platform and its services are committed to privacy protection. Privacy measures ensure compliance with legal requirements and build trust with people. Open access to data of general interest makes the district transparent for residents and users as well as other stakeholders.

However, one major challenge for us was the time-consuming construction work, which means that we have only very limited access to users of the future district. Therefore, we needed alternative ways to derive requirements and concepts for our digital solutions, as we could not ask users directly.

19.3 Technical Background

In this chapter, we provide some more details about our technical solution, which is the basis for most of the developed concepts, digital prototypes, and solutions.

The digital district platform supports the creation of applications in the context of the digitalization of the Pfaff smart city district. On the one hand, concrete applications are being developed in the project; on the other hand, it should also be possible for external partners to make digital services available in the long term. The platform provides basic services that can be used to easily create new services. The focus is strongly on applications with direct user interaction, which are provided as mobile applications or web applications. Examples of basic services are user management, application and application version management, collection of all user data across applications, deletion or anonymization of user data across applications, chat services, or image services. These basic services can be used by applications and thus make it possible to focus on the actual added value of the service. The platform is operated in a cloud-based environment that scales automatically and can therefore serve a fluctuating number of users and load. End users do not interact directly with the platform, but via the services provided on the platform.

An overview of the conceptual architecture of the platform is shown in Figure 19.1. A fundamental distinction is made between applications on the platform and the platform itself. Users mainly interact with the applications; only for cross-sectional aspects such as registration or data information is there direct interaction with the platform. The applications themselves are divided into a frontend and a backend part. The task of the frontend is to enable direct interaction with an individual user. These frontends are often apps installed on a device or web applications executed in a browser. The backend part of the applications, on the other hand, has a different requirement. It ensures that there is a regulated exchange of data between the individual frontends of the application. In the example of a chat application, the frontends of the users would send the messages to the backend, which in turn would make these messages available to exactly those frontends whose users have access to them. In addition, the backend parts of the applications also allow for inter-application exchanges. For example, an application that organizes rides could be directly integrated as a bot into a chat application.

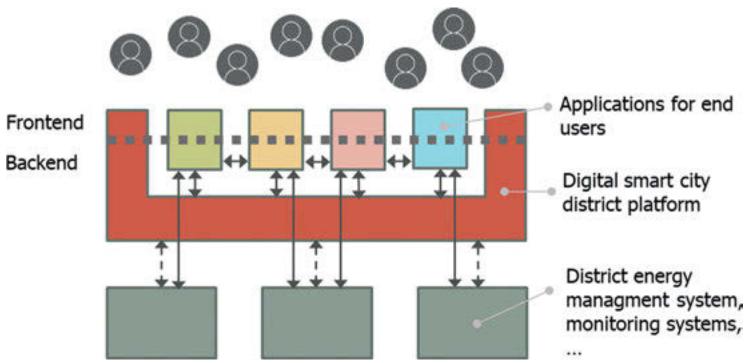

Figure 19.1: Overview of the platform concepts.

Analogous to the division into frontend and backend for the applications, such a division also exists for the platform. The platform has only few frontends since direct user interaction is rather rare, for example when registering and logging in to the platform. The main task of the platform is to simplify the backend parts of the applications. This is where the services of the platform described above come into play, which relieve application developers of a large part of the complexity in developing an application. Data is handled appropriately, and qualities such as performance, security, or the GDPR requirements are explicitly considered in our solution architecture.

As already mentioned above, due to the fact that we currently have no real users in the Pfaff district, it does not make sense to implement such a platform in the district itself. However, we needed an environment where we would be able to test new ideas, prototypes, and digital solutions. Such digital solutions often also run on a platform. However, the aforementioned platform is being developed to run and offer services, but not to test ideas and prototypes. Therefore, we decided to develop a so-called mock platform. The basic idea is to have a technical framework that offers, in particular, ways of testing new services and ideas, while neglecting qualities such as performance or privacy.

The mock platform consists of four components. The core is an event broker. All participants (services) can easily communicate with each other via this event broker. The MQTT protocol is used, which is supported by all common programming languages and IoT devices.

The second component of the mock platform are the services, which provide basic functions that are always needed during prototype development. These include, for example, cloud storage, which can be used to exchange large volumes of data, and a user service, which can be used to create and manage users.

The third component is the introduction of so-called “shared topics”. These aim to simplify communication between existing and newly added applications by standardizing communication. The selected communication rules make it possible for existing applications to receive and process messages from newly added applications without having to adapt existing implementations.

The last component is a feedback component that can be used to analyze the communication taking place over the mock platform. This component provides detailed insights into the communication of a prototype, such as average message size, sending rate, number of recipients, etc. The resulting information can be used for communication optimizations of future applications.

An overview of the used technology and concepts can be found in Figure 19.2.

19.4 Digital Application Examples from the Smart City District

In this chapter, we will show some of the concrete prototypical digital examples that we developed.

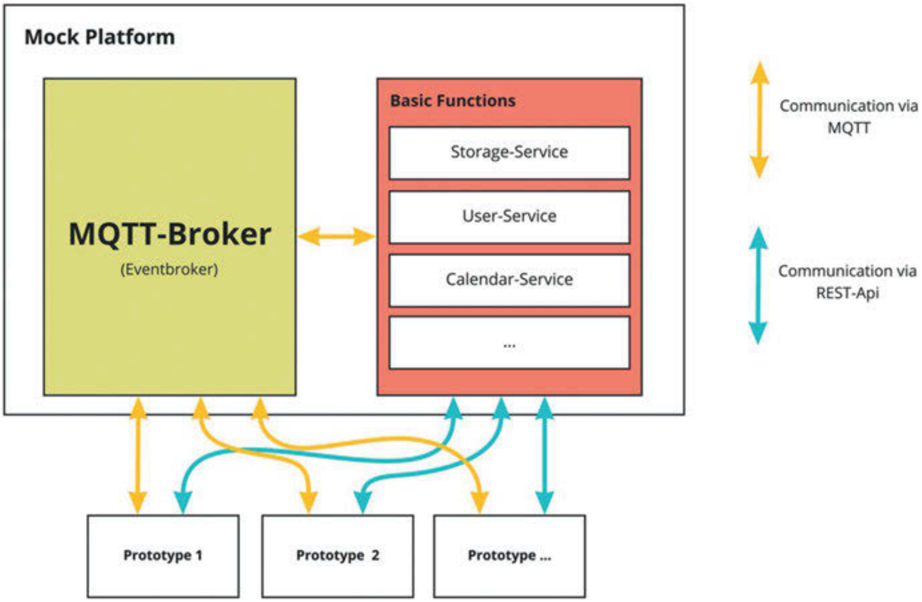

Figure 19.2: Mock platform technology.

19.4.1 MiniLautern

Imagine a district where kids can safely play near the road, where cycling is fun and safe, where space for humans is more important than space for cars. Imagine a quiet district without traffic noise but with good air quality. To achieve this kind of district, more people need to use ecofriendly ways of traveling instead of using their own car.

Behavior change all starts with realizing the good of the change, for yourself and your loved ones. We want to demonstrate the positive effects of ecofriendly mobility to people, but without giving them the feeling of being lectured or reprimanded for using their car.

Therefore, we designed the game “MiniLautern” (short for: small Kaiserslautern). The web-based game is a single-player game. At the beginning of the game, the fictional person Ellen Mask introduces the player to the task: choose mobility measures for the Pfaff district that make the citizens happy, improve the quality of life in the Pfaff district, and reduce the negative impact on the environment.

In each round, players get to know fictional citizens in the district. They can read about the citizens’ needs and regular travel destinations. There are diverse fictional characters so that the players can empathize with at least one of them. Thereafter, they select a mobility measure and receive feedback regarding the impact on environment, quality of life, and happiness.

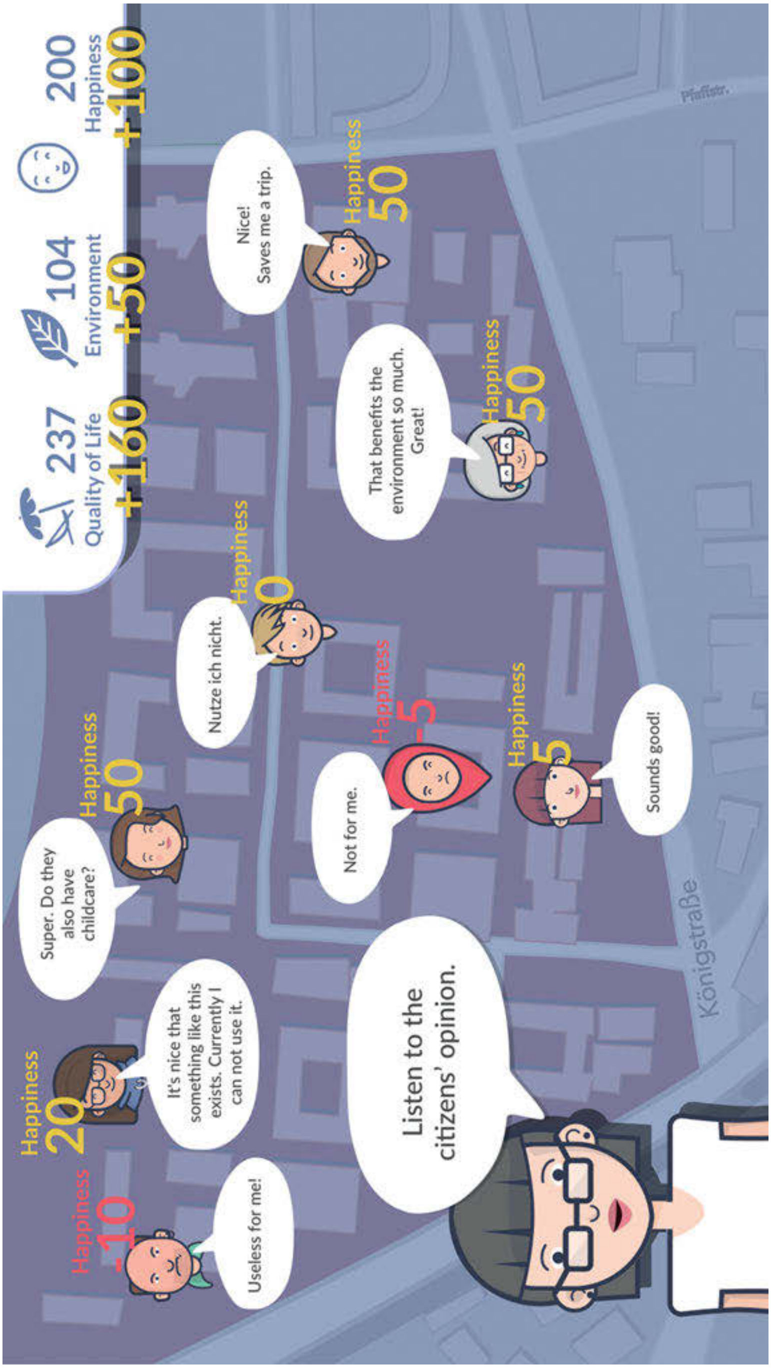

Figure 19.3: MiniLautern user interface.

In short, the game introduces mobility measures that are indeed foreseen for the district or that could be part of the district but are currently not planned. The game stresses the positive effects of the mobility measures and thereby increases the citizens' acceptance of these mobility measures.

The game can be played online.[1] It is available in German only. Further background can be found in a video.[2] Some impressions are provided by Figure 19.3 and 19.4.

19.4.2 Fish 'n Tipps App

The second example is the Fish 'n Tipps app. This solution prototype is being developed in the area of energy and community. The core idea is that a personal avatar, represented here as a fish, gives hints and tips on how to behave in a more climate-friendly way. The tips come from two sources: Elberzhager, Mennig, Polst et al. (2021) from other residents of the district and other users of the app (i.e., the community idea); EnStadt:Pfaff (2019) from the digital ecosystem itself, where our app "listens" to other apps and responds with appropriate tips. This means that users interact with the app, and several kinds of data is handled within the app. One example is that the app knows that the weather is good, there are still bikes available at a nearby rental station, and the user's next appointment is only two kilometers away; then our Fish 'n Tips app can suggest that the user can take a bike instead of a car.

The user can then decide whether they want to do that and can follow this tip. There are also gamification elements in this app, from the look and feel to "little competitions" where users can collect points. Our goal here is to provide a digital assistant that gives advice on how to save energy and offers networking between people. A screenshot can be found in Figure 19.5.

19.4.3 PfaffFunk

To provide information to interested citizens and other involved parties and to support the dialog between them and the project partners, a communication app named "PfaffFunk" (German for Pfaff radio) was developed and is available on iOS and Android. It is a variant of the "DorfFunk" (German for village radio) app developed in another research project.

PfaffFunk is a small social network in which users can exchange public posts on which others can comment. News and event announcements from the project website are also being pushed as dedicated post types into dedicated categories in PfaffFunk,

1 Available at: https://www.minilautern.de/ (Accessed: 30 April 2022).

2 Available at: https://www.youtube.com/watch?v=7Z7V9vlZBbA (Accessed: 30 April 2022).

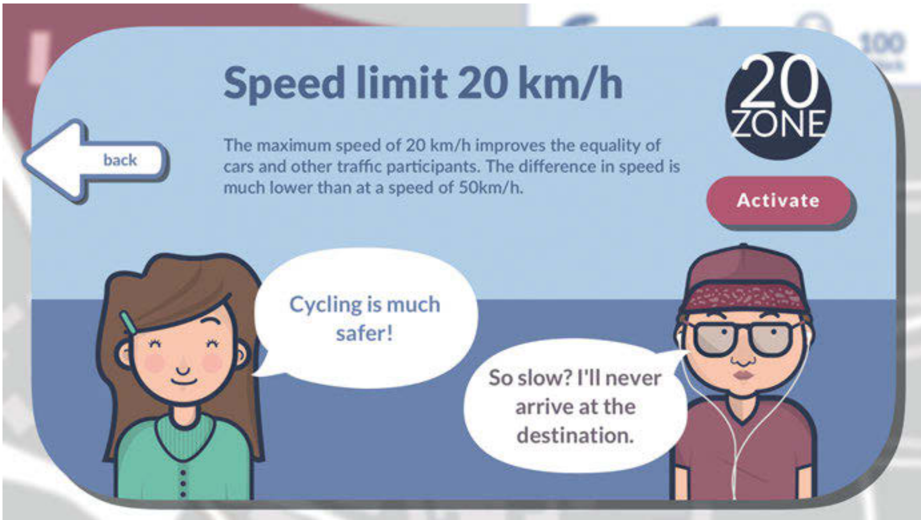

Figure 19.4: MiniLautern view on a mobility concept.

Figure 19.5: Fish ’n Tipps App.

and users can comment and like them. Users can show an interest in posted events as an indication that they want to participate. There is also a possibility to define groups, e.g., to discuss certain aspects like environmental protection. Users can also begin private chats with other users who publicly posted or commented on something. Posts can contain several images as well as post-type-specific metadata, like news category or event location and date.

Another feature of the app is an overview of other services available to the app's target group. In PfaffFunk, these services encompass the other solutions developed within the project as well as information sources, like MiniLautern or the YouTube Channel of the "Quartierswerkstatt". A different feature being developed for PfaffFunk is a feedback mechanism to allow providing feedback regarding the app's functionalities from within the app, e.g., after using a specific functionality for the first time. This is done to improve existing features and develop new features based on direct user feedback. Some impressions are given in Figure 19.6.

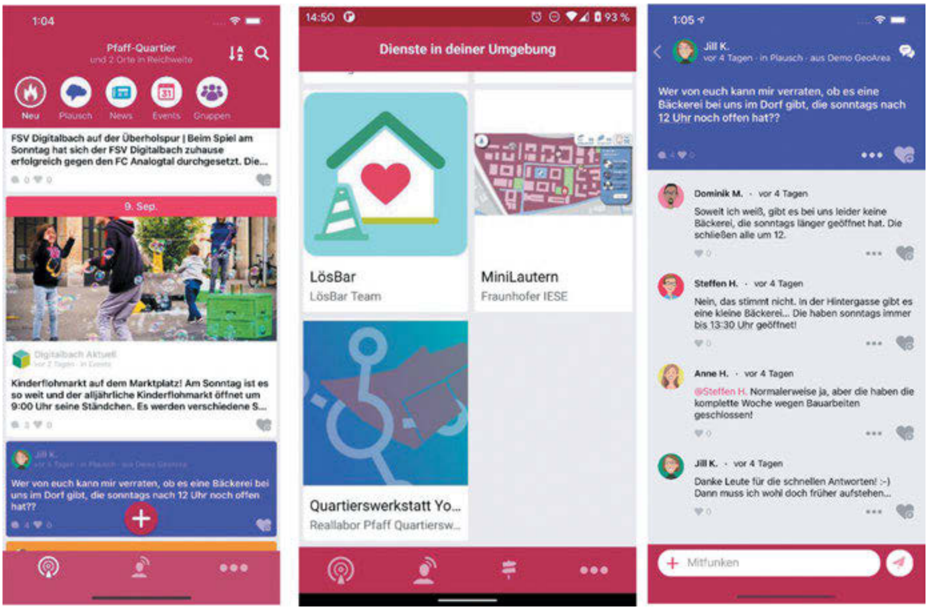

Figure 19.6: PfaffFunk app.

19.4.4 Conclusion

We have developed several concepts, prototypes, and initial solutions and showed how the digital transformation can support a climate-neutral smart city district. Of course, these can only be considered a starting point, especially due to our main challenge of not being present in the district itself because construction work is so slow. However, we developed and implemented solutions and got initial evaluation results via direct feedback from users or via questionnaires. More information can be found on our YouTube channel[3] or in Elberzhager/ Mennig/Polst et al. (2021).

19.5 Smart Home

After providing a general overview of example smart city applications, we will show in this chapter how connecting multiple individual applications within a city district platform can create synergies that provide additional value on top of the individual benefits. As an example, we chose the Pfaff smart home system, as it provides a prominent entry point into the digital Pfaff universe. A classical smart home system consists of a smart home hub, which houses a computing unit that hosts a logic to connect various sensors and actuators within a defined area.

The most prominent use case of smart home systems is their function as a multimedia interface with a strong focus on lighting installations in residential houses or apartments. Further popular applications are security systems, including camera installations and break-in alarm sensors, or ambient assisted living applications, with sensors detecting falls or emergency buttons to request help. A less popular application in the past, which is, however, making rapid gains with the increase of PV installations and wallboxes for charging electric vehicles is the topic of energy management and energy saving. Within the Pfaff project, we focused on the energy-saving aspect and asked how a smart home system can help decrease energy consumption without violating any user comfort settings. In fact, within the developed system, an increase in comfort is possible by automating formerly manual processes. Further requirements were derived from the EnStadt:Pfaff mission statement (EnStadt:Pfaff 2019), extended by a list of points we consider important for an interconnected energy-saving smart home. The requirements are listed in Table 19.1.

Table 19.1: Requirements for the EnStadt:Pfaff Smart Home System retrieved from Surmann, Bär, Heupts et al. (2019).

Primary energy targets			
1.	Save energy	2.	If energy saving is not possible, optimize the usage in the most efficient way
3.	Use local and renewable energy	4.	If no local energy is available, use external renewable energy

3 Available at: https://www.youtube.com/channel/UCK8LjvcvaCHBF-voo0qcqqA (Accessed: 30 April 2022).

Table 19.1 (continued)

Additional functional targets			
5.	Generate value for all people of various ages and with various lifestyles	6.	Guarantee comfort or increase it
7.	Provide a high-quality indoor climate	8.	Guarantee data privacy
9.	Measure and visualize energy usage	10.	Provide energy consumption for performance evaluation
11.	Create a user interface to the ICT environment and follow a user-centered design.	12.	Provide recommendations for changes in user behavior towards a sustainable lifestyle
13.	Use a resilient infrastructure	14.	Provide sensor data for other ICT apps
15.	Use open systems that are adaptable and can include various devices	16.	Be scalable for the whole neighborhood

To showcase the Pfaff smart home system, we had planned a demonstrator installation in the Pfaff neighborhood, but due to delays in the building construction and renovation process, we replaced the chosen apartment with a digital twin, including an electrical device simulation, using the Fraunhofer tool synPRO (Fraunhofer ISE 2022) and a smart home visualization (see Figure 19.7).

In addition, we installed some prominent smart home actuators and sensors on a demonstration wall and tested two smart home hubs, one open-source and one commercial product, which could both be combined with different devices from various manufacturers by using the most common wireless smart home communication protocols (Wi-Fi, ZigBee, Z-Wave, and EnOcean). The different components of the lab demonstrator and their interconnection are visualized in Figure 19.8.

19.5.1 Base Applications of the Standalone Smart Home

The standalone smart home hub can be connected with multiple sensors and actuators. When we selected these components, we did, whenever possible, choose low-energy devices, preferably devices with energy-harvesting functionality. Such devices use the available resources from the surrounding environment; for example, by using a peltier-element, the temperature difference between the radiator and the surrounding air can power a smart heating thermostat; the kinetic energy from pressing a switch can power the internal wireless transmitter; and small photovoltaic cells can provide energy for multiple sensors gathering and transmitting indoor climate data. All sensor data is collected within the smart home hub and an internal “if this than that” (IFTT) logic leads to actions being sent to other smart home devices or the user. Depending on the number of installed components, different energy-related routines are included. We clustered these individual routines, which led to four different states

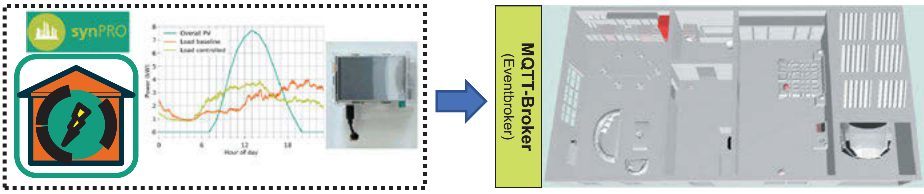

Figure 19.7: Smart home simulation, including synPRO smart home application simulation (left) and visualization (right).

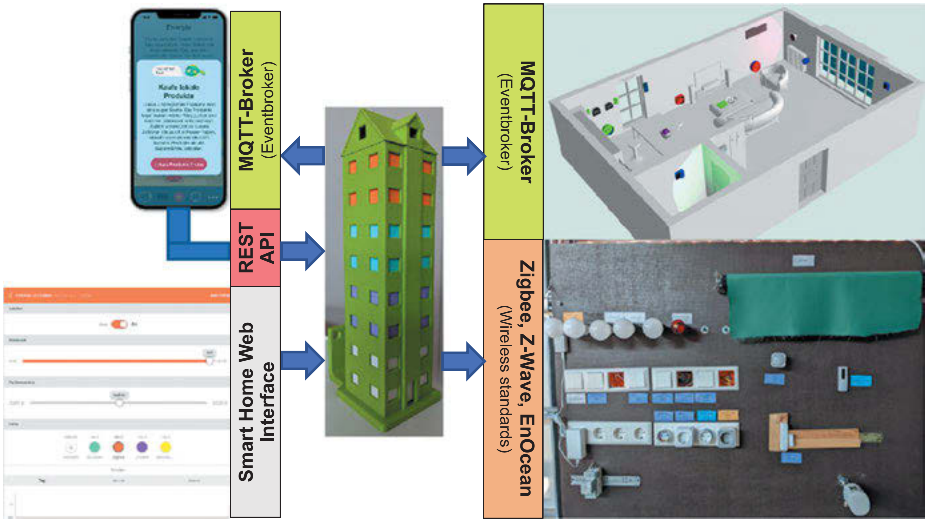

Figure 19.8: Lab demonstrator, including a smart home hub (center), smart home actuators and sensors on a demonstrator board (bottom right), a digital representation of the demo board (top right), the Fish 'n Tipps energy-saving app (top left), and the standard smart home web interface (bottom left).

("at home", "sleeping", "away", "on vacation"), which can either be triggered by automated events or by a manual action (e.g., by pressing a switch when leaving the home). A state change checks the current sensor data and predefined user settings to execute a variety of actions. Since explaining all routines within this article would be too ambitious, we will only explain one switch of states to show the general logic and give an overview of some practical IFTTS.

The initial state is "at home"; the room temperatures are set based on predefined user settings; the shutters are open; the air circulation rate within the occupied rooms works at a normal rate. Room climate sensors are monitoring the state and readjust actuators if needed. Now a user leaves the apartment, which is detected by the door sensor in combination with 10 min of no movement being detected or by the user actively pushing a switch upon departure. The state changes to "away" and the following actions are taken:

- **Electricity:** All predefined sockets are turned off, reducing the electrical demand to a minimum and only supplying freezer, refrigerator, and devices added by the user to an exception list. Additionally, the lighting is turned off.
- **Heating/Cooling:** The room target temperatures are adjusted to reduce the demand for heating and cooling. Additionally, sensors detect solar radiation and the smart home hub predicts the current thermal gains due to solar radiation. If the target temperature is below the current temperature (cooling demand), the shutters are closed. If the target temperature is above the current temperature (heating demand) and solar radiation is high, the shutters are opened; otherwise they are closed.
- **Ventilation:** Air circulation is reduced to a minimum.
- **Non-energy-related extensions:** Security devices are turned on (e.g., cameras or window/door sensors). Depending on the cleaning schedule, an automated vacuum cleaner is activated.

19.5.2 Added Value Through Interconnection

While the standalone smart home system already provides some value, its potential can be significantly increased by connecting it to other data resources and apps in the Pfaff ICT platform. The previously presented state change from "at home" to "away" can be extended further. The process including interactions with other apps and services is visualized in Figure 19.9 and explained in the following lines. Right after the state change is initiated, the user's calendar is checked for specific events. Additionally, the current GPS position of the user's smartphone is collected. With these two sources together with an optional learning database, the time of return can be estimated. This estimation could be verified by sending a push notification to the user for verification and at same time providing suggestions for possible routines or asking for further commands; or the user can stay passive and automation takes over. For example, if, on a working day, no events are scheduled for this day, but the user's GPS signal is in a different city, the application could ask the user to confirm a business trip and how many days it will take. Otherwise, if the GPS coordinates are within a specific area, no notification is sent.

The information about a current absence can further be referred to an interconnected energy management system (EMS), with the aim being to shift flexible loads to times of high photovoltaic (PV) energy supply. A detailed description of the agent-based EMS is provided in chapter 20: "Agent Based Energy Management and Blockchain Based Organization for Energy Communities". This information is used to optimize energy usage within the personal energy system and the surrounding energy system of the neighborhood.

1. If the user plans to return in the evening and a heating demand is expected for the night, or if the user usually prefers to take a shower upon arrival, the EMS could decide to heat up the domestic hot water and heating system storage using PV energy to power an electric heating system (heat pump or heating rod), thereby optimizing the user's individual energy consumption. Using the information on estimated travel time for the return trip, the apartment can be heated up, providing the desired room temperature upon arrival.
2. If, instead, the user stays away for a longer time, or if the expected thermal demand is low, the EMS could use the information about lower electricity consumption by one user together with high consumption predicted for neighboring buildings to feed PV surplus electricity into the public grid, sharing it within the Pfaff community (see red sequence in Figure 19.9).
3. Finally, if the predicted neighborhood demand is also low, the EMS could use overproduction to charge electric vehicles or, if no other target device can be supplied, to store it inside a stationary home or district battery system.

Smart charging of electric vehicles, in particular, has a large flexibility potential within the Pfaff district. It can further be enhanced by also including calendar information about the user or direct parameters, like a target state of charge upon departure to reserve some battery capacity exclusively for additional PV electricity. Additionally, bidirectional charging could be included to discharge the battery in times of high demand and recharge it later at times with PV overproduction. Information on whether the user prefers using an electric vehicle at all or would rather switch to other means of transport can be provided by certain apps, such as a mobility assistance app within the Pfaff digital ecosystem.

While weather data is needed for a good PV energy forecast, the same information provides another useful addition to a smart home system. Using weather predictions, the heating and cooling process can be optimized, not only in terms of reacting to the current weather conditions by exercising shutter control, but also in terms of considering temperature and solar radiation forecasts. In this way, the heating temperature can be reduced before solar gains can heat up the room above the desired temperature. Especially for slowly responding heating systems during spring or autumn, an anticipative system can reduce additional heating or cooling demand.

Finally, the previously mentioned Fish 'n Tipps app is linked to the smart home system, analyzing smart home usage and providing useful information, not only for automatically optimizing energy usage but also for increasing the user's awareness regarding their energy-related carbon footprint and encouraging them to change their behavior and make it more sustainable. For heating systems, the app could check the target temperatures of different rooms and provide a hint to further lower the room temperature during absences.

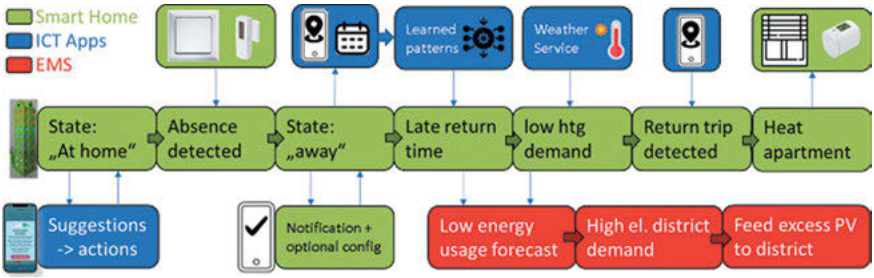

Figure 19.9: Example smart home sequence and interaction with the ICT environment.

19.6 Summary and Future Work

The digital transformation is able to support a climate-neutral smart city district in various ways. We started this chapter by explaining our general understanding of how this can be done and what the basic principles are in the development of digital solutions. We gave an overview of our digital ecosystem and described our platform and our mock platform, and presented several examples of prototypes, for example MiniLautern, the PfaffFunk app, and the Fish `n Tipps app. Here, data plays an important role as this is produced and consumed within the different apps. The district ecosystem is able to handle such data and takes care that qualities such as security or the GDPR is considered appropriately. Though we developed different solutions, they are part of one district ecosystems, which makes an integration easy. Of course, some of the applications, such as MiniLautern, is more a stand-alone solution, while apps such as the PfaffFunk or the Fish 'n Tipps app are deeper integrated and connected.

The presented smart home use case shows only a selection of possible interfaces between different applications and services. The more data sources are available, the more possibilities for smart automation emerge. The topic of machine learning, in particular, was only briefly tested by us with regard to user pattern analysis. When linking different applications within the ICT universe in order to reduce energy consumption and increase comfort, the topic of data privacy jumps into focus. For this study, we did not work on the network security part or on data encryption, but instead used an MQQT broker with clear messages displayed to be used by any service. Guaranteeing secure handling of personal data is a topic for a real–world implementation. In any case, the user can always decide what apps can access and provide what data and whether any synergies should be used at all.

The challenge of the slow construction work in the Pfaff district made it especially difficult to test our solutions in the district itself. This is one major open issue for future work.

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Arne Surmann, Manuel Utz

20 Technologies for Climate Neutral Districts: Agent Based Energy Management and Blockchain Based Organization for Energy Communities

Summary: This paper presents an agent-based decentralized energy management system for sustainable energy district systems based on renewable energies. An agent has the sovereign control over a flexible device and fulfils individual targets set by its owner, while following community set targets incentivized by PV asset tokens stored within a blockchain. This setup enables the development of a heterogeneous energy community. We demonstrate the operation of an exemplary agent for the bidirectional control of an electric vehicle and show how the blockchain based incentives could be implemented in a scenario where a local utility company functions as energy community operator. Results show that the decentralized optimization enhances the PV self-consumption within the EC and tokenized PV shares provide a feasible solution for active prosumer participation.

20.1 Introduction

The energy system is undergoing a major restructuring process away from a fossil based and centralized system towards a decentralized structure based on renewable energy sources. This provides various challenges. How can we produce enough renewable electricity to not only cover today's demand, but also to foster electrification of the heating and mobility sector? How can we match consumption with the volatile electricity production of wind and solar plants – spatial and temporal? And how can this be done in a socially acceptable way where citizens are able to actively participate and profit from the structural change? A lot of research is trying to answer those and other questions, forming a path into a carbon neutral future. Within this work we provide some possible solutions to answer those questions bottom-up from the district perspective.

Arne Surmann, Fraunhofer ISE, Germany
Manuel Utz, Uni Bayreuth, Germany

https://doi.org/10.1515/9783110777567-020

20.1.1 Enabling Bottom-Up Energy Community Participation

Within city districts a major challenge is to utilize the potential of unused rooftop areas and to install as much PV generators as possible, to produce electricity directly where it is consumed. In cities, this is the only realistic source of carbon neutral electricity production and today, especially on multi-party houses, it is barely used. This is mainly due to the complex regulatory framework. Additionally, individual parties living or having businesses within the buildings have hardly any possibility to jointly install PV generators on the rooftops. One attempt to overcome the lack of PV panels in German cities was made by the introduction of tenant electricity, which still entailed high regulatory hurdles and did not bring the expected increase in district PV installations. The effects of the tenant electricity concept on optimal system design and profitability within multi-family buildings was analysed by (Braeuer/Kleinebrahm/Naber et al. 2022) where the authors found a profitability but also noted the high complexity of investment decisions. In any case, even if the tenant electricity concept would have succeeded, it would still have been a solution where an external entity sold PV energy to the passive consumers within the building – on a price discount but without any active prosumer participation. On an EU level the recast of the renewable energy directive (RED II) demands the possibility for active prosumer participation within the energy transition and formulates the idea of renewable energy communities (REC). In (Lowitzsch/Hoicka/van Tulder 2020) the authors conclude that RECs under RED II can be a useful facilitator for future energy systems. Since RECs are characterized by heterogenous actors which are organized in a distributed manner, blockchain networks are a promising choice for organizing those. (Andoni/Robu/Flynn et al. 2019) divides the blockchain applications within the energy sector into eight categories with "decentralized energy trading" being the largest in terms of applications. This is a particularly popular use case within energy communities, as demonstrated in (Lüth/Zepter/del Granado et al. 2018) for a community in London or by (Tsao/Thanh 2021) within a simulation study on micro grids. While trading of energy is already investigated in detail, studies on the representation of RE production sites such as PV generators are still sparse. In this context, we developed a smart contract-based system that can organize PV ownership structures in a simple, fast, and verifiable way. With this system consumers can either jointly invest in PV generators and have a digital ownership right or the system is installed and operated by a municipality that invests in the PV generator and afterwards rewards PV shares for energy system beneficial behaviour. With the blockchain in place, other services are possible to further organize the district energy system and to keep track on financial and energy flows. Especially, the topic of energy sharing is of high importance. Matching local consumption and production pattern might further increase the community self-consumption and self-sufficiency. Those two organizational aspects – PV ownership and energy sharing mechanisms – utilizing blockchain technology are presented in section 20.3.

20.1.2 Management of Distributed Energy Systems

Within the previously described energy district, forming an energy community, we face a distributed energy system with a heterogeneous ownership structure with individual and community goals. Apart from the PV plants, there may also be flexible production and consumption units, e.g., battery electric vehicles (BEV), heat pumps (HP) or stationary batteries. Managing such a decentralized system with multiple sources and sinks of electricity owned by various actors can best be done in a similar decentralized way. In (Fernandez/Hossain/Mahmud et al. 2021) the authors developed two optimisation frameworks to show how local energy markets and energy sharing can best be managed in an energy community. While this study yields promising results, the control scheme is done in a centralized way with perfect market knowledge, which is less suitable for a practical implementation within the context of heterogenous REC. In this context (Li/Pan/Xu et al. 2021) propose a decentralized competitive peer-to-peer control scheme for district heating and cooling using IOTA (https://www.iota.org/) which provides a suitable framework that could also be applied on electricity trading. However, within the current German regulatory framework peer-to-peer trading is not feasible.

Therefore, we combined an external billing mechanism with a decentralised optimization approach to have bottom-up control with legal incentives as optimization targets. We developed an agent-based energy management system where multiple agents keep track of their individual owners' targets and jointly work towards the community goals of maximizing PV self-consumption while minimizing grid peaks at the distribution grid level. The system is presented in the following section 20.2.

20.2 Agent Based Energy Management Within Energy Communities

A typical neighbourhood consists of various independent parties with various motivations and different devices operating within the energy system. In the context of the project EnStadt:Pfaff we aim for a mixed commercial and residential neighbourhood where offices, restaurants, shops, and residential units for different users with different socioeconomic backgrounds are planned. In terms of energy management, the Pfaff system is mainly focusing on the electricity sector, since a high temperature district heating system is planned, without any power to heat devices. Two sources of electricity are present, PV plants on the roofs and facades of the buildings and external energy from the public grid. The major flexible devices are charging stations and stationary battery systems, followed by cooling and air-conditioning. However, since heat pumps are playing a major role within future energy systems, we included those in the development process as well.

20.2.1 What is the Best Control Scheme for a Neighbourhood?

When talking about energy management systems, two different designs are possible:
1. In a **centralized approach** all the data about the current state of the energy system is sent to a central computing unit that calculates an optimum and sends back control signals to specific devices.
2. In a **decentralized approach** only a limited amount of state data is gathered from only one or a few devices. This is computed by individual units near the devices and an optimum control is applied on the limited device pool.

Both methods can either be used in direct proximity to the energy system, or a cloud solution can be chosen, where in the decentralized approach the energy management is still divided into subsystems that act autonomously but the computing unit is a cloud server that can be placed anywhere. Additionally, hybrid solutions which are not fully centralized but neither fully decentralized are possible. The pros and cons of a decentralized energy management are listed in Table 20.1.

Table 20.1: Pros and Cons of decentralized energy management.

Pros	Cons
High resilience, no single point of failure	Harder to find an optimum, possibility of oscillation
Easy scalable/ adaptable	Potential for contradicting individual goals/ behaviour
Private data stays private	Higher communication demand
Individual targets/ configuration possible	More control hardware devices needed*
Control close to the target device*	

*Unless a cloud solution is established

A decentralized EMS has the advantage of not providing a single point of failure. If a centralized computing unit fails, the whole EMS fails, while in a decentralized approach only a corresponding subsystem fails while the main body of the EMS is still working. In addition, the system is easily adaptable by simply plugging in another control device and connecting it with its dedicated energy devices and the EMS network. Another pro argument is the private behaviour of the decentralized system, private data stays within an encapsulated subsystem and individual targets can be followed without a central system overruling individual control decisions.

On the other hand, finding a system wide optimum is harder when different sub targets, that may even be contradicting each other, are present. Defining the right incentives is therefore key to a decentralized EMS where a consensus about a common optimum is desired. Finding this optimum can take multiple iterations of communication between the subunits and in the worst case an oscillation of the system can occur when sub-EMS change between two states trying to adapt to the also changing information from other sub-EMS. Finally, if the decentralized EMS is installed directly at the dedicated devices, a lot of independent hardware needs to be installed which is costly and may be a waste of resources at the benefit of increasing the resilience against communication downtime. This last part is only applied if physical devices are present. In a cloud-based solution the amount of hardware devices is reduced at the cost of needing an additional communication network to communicate with the energy system.

For the project EnStadt:Pfaff a hierarchical decentralized approach with two different aggregation layers was chosen, where decentral computing devices are further referred to as energy agents, or simply agents. This topology is best suited for the heterogeneous structure of an energy community.

20.2.2 What is an EnStadt: Pfaff Energy Agent?

According to the VDI/VDE standard 2653 "a technical agent is a delimatable (hard- and/or software-) unit with defined goals. A technical agent tries to reach those goals by autonomous actions and by interacting with its environment and other agents" (VDI2653). In this context an agent can have various degrees of autonomy, cognitivity, sociality, activity, adaptivity and robustness. Within the EnStadt:Pfaff project different types of agents are present for specific controllable and non-controllable loads and generators. A schematic overview of an agent with a connected controllable device is presented in the left part of Figure 20.1.

It has 4 interfaces to interact with its environment:

1. The **communication** interface is implemented using zeronet (https://zeronet.io/) a peer-to-peer chat using the BitTorrent protocol to connect the agent with other agents. Within the Pfaff project it is used to communicate energy forecasts or plans.
2. The **blockchain** interface is an Ethereum full node in a private chain where different smart contracts can be addressed which provide incentives to work towards a common goal. Ethereum was chosen since it is the most established smart contract-based blockchain protocol where many other blockchains derived from. Other smart contract-based protocols are also possible (e.g., an implementation within the energy web Multi-Verse www.energyweb.org)
3. The **user** interface provides the option for a user to set specific targets and to add information on planed behaviour for better energy schedules. (Note that this can be done using the smart Home Interface and data from the ICT platform as introduced in "A climate-neutral smart city district supported by digital solutions" section "Smart Home" in this anthology.)
4. The device interface is implemented as a REST connection that directs messages to and from the openMUC (https://www.openmuc.org/) translator, which has various communication protocols implemented to exchange messages with a specific energy device.

With those four interfaces, the agent interacts with its environment and collects data to calculate an optimum schedule for a connected controllable device. This calculation is done within the central “decision making” module. In a nutshell, the agent calculates an optimal operation of the flexible device first fulfilling the user targets and second by following common market incentives. Those plans are communicated with other agents, that use the information within their own optimization. A small-scale multi-agent system is shown in the right part of Figure 20.1.

20.2.3 Exemplary Optimization of a Battery Electric Vehicle

In the EnStadt:Pfaff context the BEV optimization was detected to have the highest expected impact on the energy system. The BEV optimization is shown in Figure 20.2. A pricing mechanism was implemented with the aim to maximize local PV consumption within the community. It differentiates between three sources of energy (from cheapest to most expansive):

1. Internal PV (**IPV**): PV energy produced and consumed within the same building
2. External PV (**EPV**): PV energy produced on another building within the district
3. **Grid**: Energy provided via the public grid

This pricing mechanism provides the common incentive for agents to maximize their revenue by consuming PV energy. In the BEV context this means, by rescheduling the charging process to guarantee the user specific target SOC at the user defined departure time utilizing the maximum PV dedicated, while keeping in mind the communicated energy usage of other loads within the system. Those state variables are shown in the left part of Figure 20.2. The corresponding optimization is visualized in the right part of Figure 20.2. The schematic is structured into 4 different columns. On the left 4 different chronological stages are written. In the middle bar plots show the three different energy sources in a timeseries. On the right a battery storage is visualized where the planned energy packages used within the planned timesteps are aggregated to reach the target SOC and the corresponding energy costs for the current planning step are shown. In the first stage “Shares”, the availability of the different energy sources within the planning horizon (e.g., 24h into the future with a 15min resolution) is gathered from the communication interface, together with the information of the arrival SOC, communicated from the electric vehicle via the charging station, and the target SOC as user input (default 80%). In the second step “IPV”, the optimization checks whether its dedicated internal PV share is sufficient to fulfil the target SOC, which is not the case in the example. The same process is used in the “EPV” stage with the external PV source that is added on top of the already planned IPV usage limited by the maximum charging power. In the last step missing energy is planned to be used from the grid. Note that while PV energy is always utilized as soon as possible, grid energy is planned to be charged close to the departure time to fur-

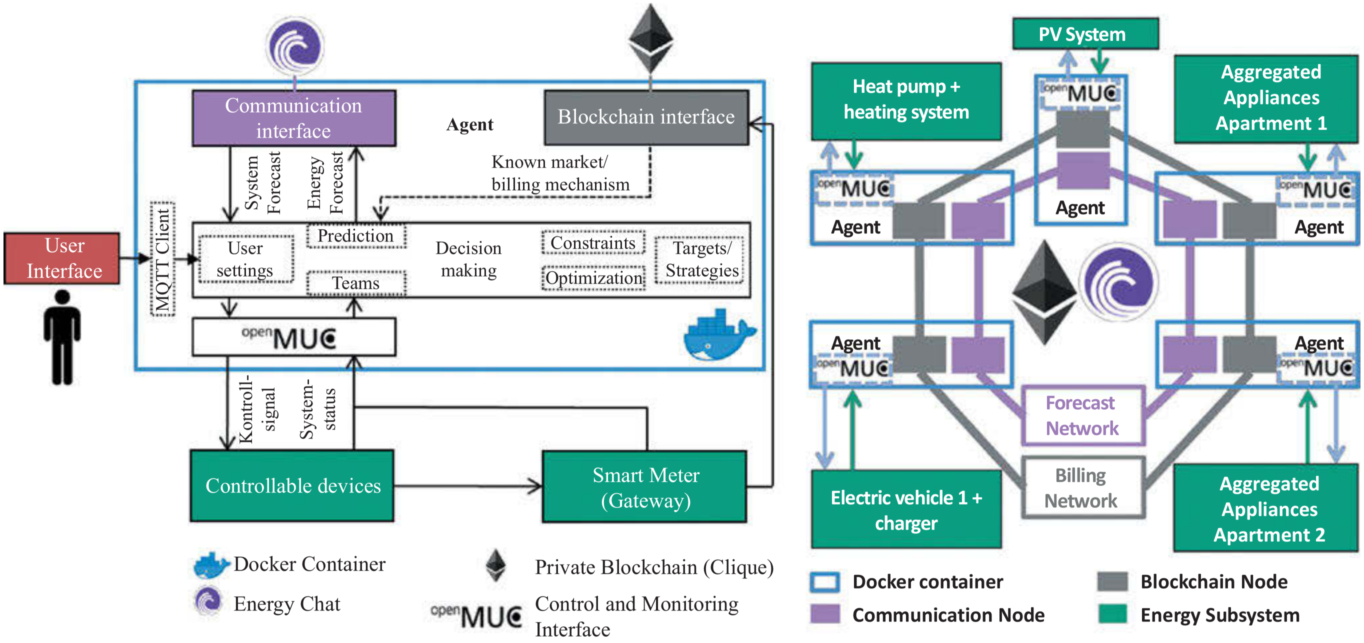

Figure 20.1: Left: Components of an individual agent. Right: Interconnection of a multi-agent system.

ther increase the PV share in case the forecast or plans of other agents change during the parking time.

This basic charging optimization is extended by a two-level optimization approach where the initial agent pool is split into multiple sub–pools which are referred to as “teams” and a second level which connects the teams and is called “community” level. A team could be formed by all agents of one user (e.g., BEV agent, PV agent and smart home agent), or following the example above by all agents within one building that jointly consume IPV as visualized in Figure 20.3. This also offers the possibility to incentivize bidirectional charging where the BEV agent not only optimizes the charging process itself but also keeps in mind the schedules of other team members and can decide to discharge into the building (Figure 20.3 left part 16:00–23:00), providing energy for non–flexible devices and later charge with excess PV energy to still fulfil the target SOC with cheap renewable energy (Figure 20.3 left part 9:00–15:00). The multi-level approach offers another advantage over the one level communication layer which is a reduction of communication messages, since first a smaller pool agrees on an optimal energy usage, before the team jointly interacts with all other teams within the community (Figure 20.3 right part visualizes the two-level communication).

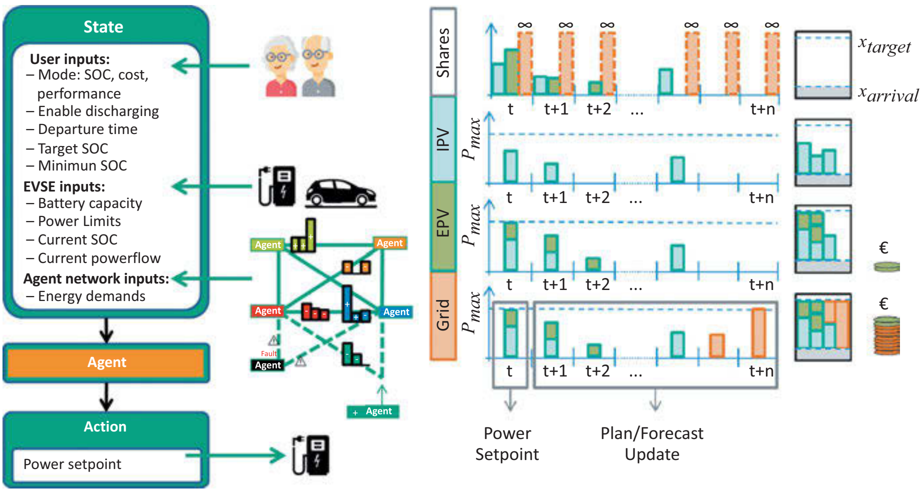

Figure 20.2: Smart charging of an electric vehicle. Left: input parameters of the corresponding agent. Right: Schematic of the internal agent logic.

While this is only one specific BEV optimization strategy, the basic idea of the multi-agent approach within the neighbourhood and/or energy community setup should be clear. Other flexible agents will have different device specific constraints and user specific target. However, the optimization following the market mechanism guarantees the common goal of a maximum PV utilization.

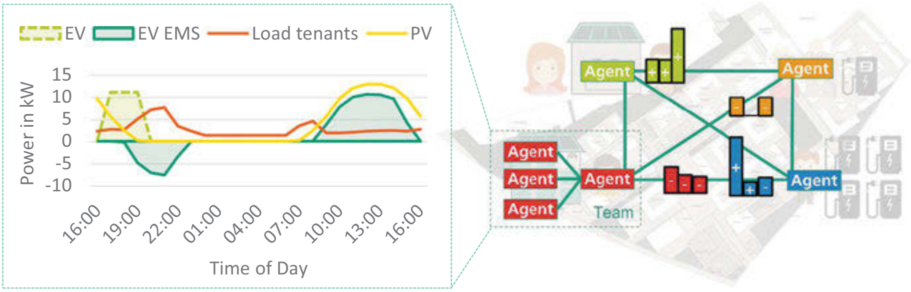

Figure 20.3: Two-level optimization approach. Left: EV scheduling. "EV" represents the "charge full power upon arrival" control "EV EMS" shows the agent-based team specific EMS with discharging enabled. Right: Schematic overview of the communication layer.

We showed that a multi agent energy management system is a good solution for a decentralized energy system with multiple independent parties within a neighbourhood to follow a common goal. In this context the question arises of how such a common goal can be implemented in a trusted environment, for which we will provide a possible solution in the following chapter.

20.3 Blockchain Based Organization of Energy Communities

How can a neighbourhood be organized, so that all involved parties find common consent of what is the state of the energy system and how the internally produced energy is divided between the different residents and companies? One answer could be by tasking a third party, such as the local municipality to do so. While this is a possible solution, within the project EnStadt:Pfaff we investigated the problem whether the neighbourhood forming an energy community could establish a technical solution which self-governs the system. In this context a blockchain with dedicated smart contracts can provide transparent incentives for the previously presented agent system to follow common goals. Transactions can be stored in a secure and trustful ledger and digital ownership rights of distributed PV assets can be generated and traded.

20.3.1 PV Asset Allocation Via Smart Contracts

While a perfect energy community would imagine several parties within the EnStadt: Pfaff district to jointly buy PV assets together and govern their own energy system, this scenario is unlikely. First, because the stakeholders – those are people owning apartments and business units, together with people living and companies operating within the district – are not yet known. Second, to perform the initial creation process bottom up without a professional player is ambitious. Therefore, a solution was developed where one central entity already present within the neighbourhood; in our case the municipal utility company; would invest in various PV plants and become an energy community operator. Thereby a long-term partnership is guaranteed where the utility delivers any missing electricity that could not be produced within the building or the Pfaff district. In addition, to pay back the initial PV investment, in the beginning the utility sells the PV together with the remaining grid energy to the community. Gradually, while the investment is paid back, shares of the PV plants are distributed to the community, slowly enfolding the prosumer-based energy community. This PV asset share allocation system is divided into two layers: (1) Energy balancing layer and (2) Token layer (see Figure 20.4).

The core element of the energy balancing layer is the "Energy-Balancing Contract". This smart contract contains the electricity quantities at each point in time to which each actor is entitled according to its previous shares of PV assets, together with the individual consumption. Several interlocking functions of the balancing contract calculate the surplus or shortfall of the power demand of the respective team from the available amount of power. After completion of this calculation, the ratio between IPV and EPV (see chapter 20.2.3) is calculated for each team individually. Here, the electricity quantities obtained from the own PV shares are set at 0€/ kWh. To calculate the individual bills a smart meter system with a 15min resolution is required, measuring all energy flows for the different teams and the grid exchange with the community.

The values calculated in the balancing contract are transferred to the "Green Energy Token Contract" located in the token layer. The main task of this contract is the calculation of the "Green Energy Token" (GET) to which the teams are entitled and their distribution to the team accounts. These are blockchain wallets. The higher the amount of electricity generated from the EPV shares (at start 100% of the PV is EPV as it is owned by the utility), the higher the number of GETs that will be distributed. Currently, the ratio is defined at 1:10. This means that each kWh from EPV is compensated with one GET, while ten kWh from the grid are required.

In the next step, the owners of the blockchain wallets can redeem the GETs they receive for tokenized PV plant shares. The third smart contract, the "Marketplace Contract", is used for this purpose. The desired number of GETs is transferred to it and PV asset tokens are distributed at a ratio of 500:1. For the deposit of 500 GETs, 1 PV asset token, which corresponds to 0.1 kWp of installed capacity, is distributed.

Due to the described mechanism of recording consumption and generation data via smart meters, calculating the shares of own and third-party electricity to which the respective team is entitled, distributing GET, and then exchanging GET for PV asset tokens, the PV system shares of the utilities are constantly decreasing while those of the teams/households are constantly increasing, enabling the grows of a prosumer-based energy community as imagined by the European renewable energy directive (RED II). The whole process is stored in a transparent and verifiable way within the blockchain

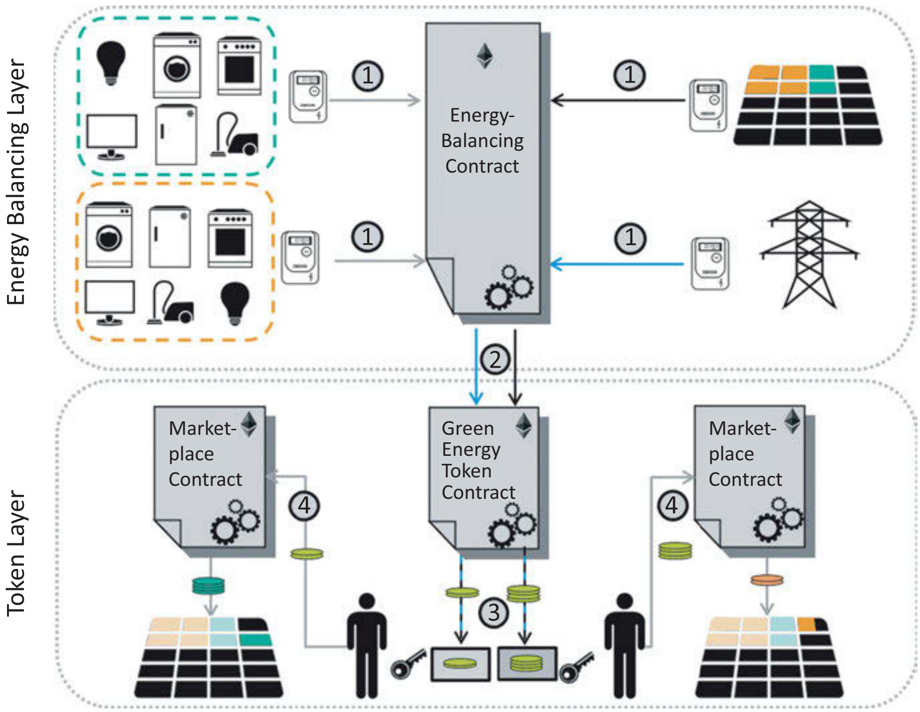

Figure 20.4: Prosumer asset ownership system structure. 1: Collection of electricity sources and drains. 2: Energy balance transfer to the GET contract. 3: GET payout. 4: GET exchange for PV assets.

system. Thereby energy agents receive a trustful incentive to utilize local PV energy. Consuming energy from its teams' own shares (IPV) comes with a direct cost benefit, consuming EPV generates additional GET that can be traded to further increase the PV share.

For an implementation of the described system, we chose an Ethereum based private blockchain with a proof of authority mechanism where the utility was set to be the validator. This setting with one governing entity is due to the regulatory framework in Germany where no real community-based solution is possible. However, the whole mechanism with PV assets represented by tokens and a reward GET for energy system beneficial behaviour can be implemented on various smart contract based blockchain protocols and is most useful for self-governing EC with changing heterogeneous ownership structures. The blockchain was set to be private since any interactions with the chain is restricted to members of the EC. Using a public chain instead, the same smart contracts could be deployed on different nodes where the access would need to be restricted to certain accounts present within the EC. For a showcase community we believe in a private chain, while for scaling up such a system a public chain with restricted SC access would lower the entry boundaries for a community to join.

20.3.2 The Pfaff Energy Community App

Since the digital literacy of households varies within the heterogeneous Pfaff neighbourhood (see chapter 20.2) but is important for the understanding and acceptance of the blockchain-based asset ownership systems (Utz/Johanning/Roth et al. 2022), the "Pfaff Energy Community App" was developed (see Figure 20.5). In designing the prosumer asset ownership program, four design principles were identified as particularly relevant. The first is to give households room to manoeuvre. For example, the ratio of GET to PV asset tokens is fixed, however households can choose to potentially redeem their GET for other services within the Pfaff neighbourhood. An example of this is the mobility services that could be paid for with GETs. The second design principle is to make verifiable information easily available to households/teams. For example, while consumers' electricity consumption is recorded automatically via smart meters, it is the intuitive Energy Community app that displays this in a high temporal resolution in relation to their own generation capacity. The third design principle is to create a sufficient abstraction between technical complexity and usability. The described processes and the interlocking of the individual smart contract functions are technically complex, but the result (i.e., the distribution of GETs or the redemption of GETs for PV asset tokens) is comparable to well-known bonus programs. The fourth and final principle in the design of the PV asset ownership system is to present consumption and payment data in an easily understandable and accessible way. Derived from these principles, the following four key indicators are displayed to households in the Energy Community App: (1) Self-sufficiency (for the individual view: together with the next target to reach a higher rank) (2) Earned GET as a share of the maximum possible tokens (when consumption and production match perfectly) (3) CO2 saved compared to the maximum savings possible when consuming 100% of the local solar production and (4)Cost savings on the electricity bill.

20.4 Discussion and Outlook

The system was designed to be implemented within the EnStadt:Pfaff project. However, during the project time it became clear that an implementation in a reasonably large scale was unlikely. This led to a EnStadt:Pfaff specific development in the first half of the project followed by a more generalized approach in the second half. The original device interface was modified so that instead of a REST call which is translated by the openMUC library into device specific commands it is sent directly to an

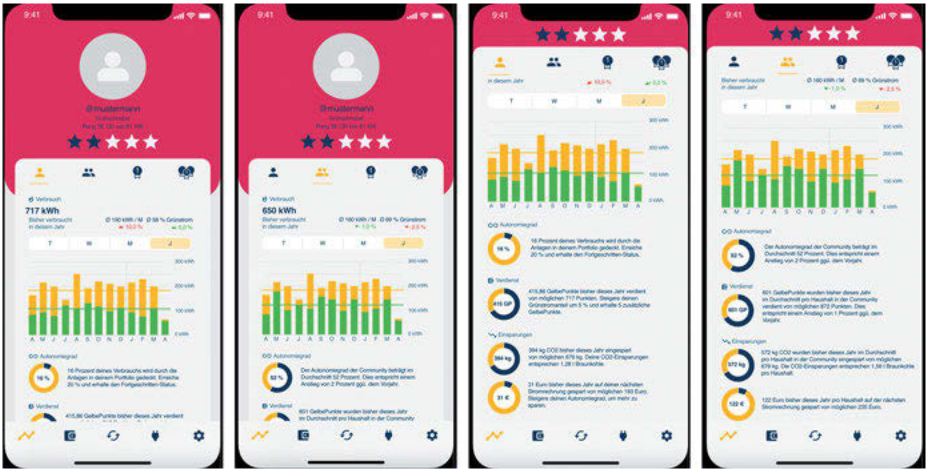

Figure 20.5: Community App showing the current statistics about energy consumption together with the financial and environmental impact.

EMS test environment within a simulation framework explained in (Surmann/Chantrel/Fischer et al. 2019). With this setup different electrical devices such as electric vehicle charging stations, heat pumps, PV-battery systems or μ-CHPs could be simulated to test the distributed agent optimization.

Additionally, different blockchain applications, different market mechanisms and optimization targets were inspected with the focus on laboratory tests instead of investing time into the specific device communication and implementation within the Pfaff neighbourhood. The agent demonstrator and the schematic representation is shown in Figure 20.6.

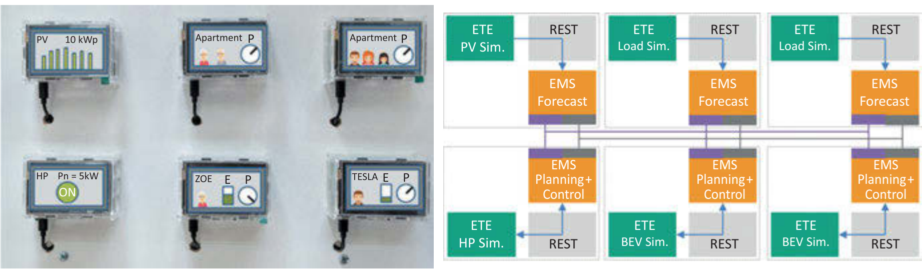

Figure 20.6: Agent demonstrator board within the lab test bed. Left: six raspberry pis installed on a portable board. Right: schematic overview of the board including the EMS module (agents), the communication network (purple), the blockchain network (grey), the REST interface and the EMS test environment with different energy system simulations).

One major challenge within the topic of energy communities and energy district optimization is the lack of a beneficial regulatory framework. While it makes sense to jointly optimize an energy system instead of having various individual home EMS, current legislation only promotes self-consumption within single family houses and to a limited extend within tenant electricity projects. While the EU demands for energy communities also regarding an active people involvement national legislation in Germany has no incentives to share or trade PV energy between different houses over a public grid. In the described blockchain smart contract setup we tried to overcome this boundary by creating tokenized incentives that enable virtual self-consumption and virtual energy sharing. In fact, the ownership of the PV system will still stay with the utility and no energy trading across building borders takes place. However, a municipal utility could still operate the above-mentioned system, directly benefiting the end consumers and encouraging energy system beneficial behaviour, while still making profit from delivering the remaining energy.

The usage of blockchain as an infrastructure was chosen to get some practical experience with the technology. While setting up sophisticated smart contracts is possible, and an on-chain calculation of energy shares can be done it is questionable whether it is beneficial to track each kWh in the blockchain. First, due to data privacy issues and second since after the values are processed and the billing is settled storing all the historic consumption data is not needed. While deleting data from the blockchain can be done (e.g., by simply setting up a new chain after a billing period is finished) it is not the core feature of blockchains (data immutability). Therefore, in a future version of the PV asset allocation system, it is planned to use the smart meter gateway infrastructure for measuring the energy flows. After all data of a 15min interval is collected an automated energy balancing can be triggered off chain with a small python program replacing the energy balancing layer (see Figure 20.4). The resulting GET claim is then directed to the GET contract to transfer GET to the member accounts. The marketplace contract together with the tokenized representation of the PV assets stay on-chain.

Additionally, in a scenario with one big player operating the whole community (e.g., the municipal utility) the advantage of decentralized governing mechanisms within a blockchain is questionable. Therefore, we conclude that for fully decentralized EC with heterogeneous actors trying to find a consensus about the state of the energy system a blockchain solution is an excellent tool, preferably with a low energy consensus mechanism. For example, a private Ethereum based chain with a proof of stake mechanism could be a solid choice. For scenarios with a central player involved as presented in this paper a proof of authority consensus mechanism was used with the utility being the only validator, trusting this party a centralized database would be a sufficient solution and can replace the need for a consensus mechanism. In any case, a detailed measurement of the energy flows with time resolutions of at least 15min is needed to operate the described agent-based EMS and should be possible by using smart meter gateway infrastructure.

Finally, future applications of the GET apart from redeeming those for PV assets will be investigated. An exchange for car sharing usage was discussed within the project consortia. Other possible applications are the purchase of smart home devices or the usage of GET as a local currency (similar to existing loyalty programs).

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Sebastian Gölz, Christian Bär, Diana Berg, Frank Elberzhager,
Jens Frank, Martin Kohl, Alexandra Rode, Stefan Staehle, Jörn Zitta

21 Learning from Climate-Neutral Neighbourhoods: Social Scientific Work in the Living Lab EnStadt:Pfaff

Summary: "What is needed in addition to achieve climate-neutral neighbourhood development?" This question pose many urban planners, planning authorities, architects and other related professionals. The Living Lab project EnStadt:Pfaff provides a place of learning where learning on the real-world problem 'Creation of a climate-neutral urban district' not only becomes possible, but also contributes to the analysis and processing of the problem with concrete scientific and transdisciplinary methods. In this article, we present some of the activities that can be classified as real-world learning and outline their intentions and learning goals. As it is expected that learning will continue throughout implementation and continues even then the quarter will be in operation, several activities are currently carried out in the Living Lab project to enfold their impacts in the next years. Accordingly, the approaches and the intended impacts will be described only.

21.1 Introduction

In the planning phase, the Living Lab provided workspaces to develop concepts and decision-making tools in cooperation with the practice partners to achieve the goal of climate neutrality from a technical, structural, and building perspective. These workspaces enabled a comprehensive learning on a climate-neutral urban energy system among all participants – from research, municipal administration, and political parties from the municipal council.

Learning in the Living Lab Enstadt:Pfaff occurred in this stage in three dimensions: First of all individual competence of the partners were developed further. Secondly, social learning between actors ('stakeholders') from various professional domains was required for reliable solutions, and thirdly, collaboration between different scientific disciplines

Sebastian Gölz, Fraunhofer Institute for Solar Energy Systems, Germany
Christian Bär, **Diana Berg,** Stadtverwaltung Kaiserslautern, Referat Umweltschutz, Germany
Frank Elberzhager, **Martin Kohl,** Fraunhofer Institute fuer experimentelles Software Engineering IESE, Germany
Jens Frank, Hochschule Trier - Umwelt-Campus, Germany
Alexandra Rode, Hochschule Kaiserslautern, Institut fuer nachhaltiges Bauen und Gestalten (INBG), Germany
Stefan Staehle, Frankfurt University of Applied Sciences, Post-War Modernist Housing Research Lab Bauingenieurwesen, Germany
Jörn Zitta, Mannheim, Germany

https://doi.org/10.1515/9783110777567-021

(interdisciplinarity) and between science and practice ('transdisciplinarity') led to the co-production of applicable knowledge. (cf. Singer-Brodowski/Beecroft/Parodi 2018)

From a practical point of view, the three learning perspectives were subsumed from the beginning of the Enstadt:Pfaff project under the question "what is needed in addition to achieve climate–neutral neighbourhood development?". Already in the early conception phases of the Living Lab project, the participants from science and practice shared, to a greater or lesser extent, the assumption that the achievement of the goal of climate neutrality after successful development will not be due to planning alone but will come about through diverse learning processes. This assumption corresponds with the model of the transition circle (Schneidewind/Scheck/Augenstein et al. 2011, Loorbach 2007; 2010), which is run through – also repeatedly – for successful learning on real world problems.

Taking the perspective towards future implementations in the marketing and construction phase the adaptation of existing processes, criteria, and instruments to bring the objectives anchored in the planning is inevitable. Learning will continue and hopefully spread also to other cities and municipalities to successfully transform many urban quarters towards climate neutrality. Therefore, the project EnStadt:Pfaff is also understood as a place of learning (in the sense of Education for Sustainable Development (ESD), cf. UN Decade 2005–2014), where learning on the real-world problem (Brundiers/Wiek/Redman 2010) 'Creation of a climate-neutral urban district' not only becomes possible, but also contributes to the analysis and processing of the problem with concrete scientific and transdisciplinary methods.

In this article, we present some of the activities that can be classified as real-world learning and outline their intentions and learning goals. As it is expected that learning will continue throughout implementation and continues even then the quarter will be in operation, several activities are currently carried out in the Living Lab project to enfold their impacts in the next years. Accordingly, the approaches and the intended impacts will be described only.

21.2 Completed Activities for Real-World Learning

21.2.1 Participation of Potential Stakeholders in Neighborhood Planning (Staehle/Zitta)

The participation of potential stakeholders in planning processes of climate-neutral neighbourhoods provides the basis for the understanding of learning processes in the Living Lab context as Singer-Brodowski, Beecroft and Parodi suggest. Sustainability issues increase the complexity of urban planning. The "diversity of causal linkage patterns" (Schneidewind 2014) includes the integration of scientific knowledge and stakeholder participation in planning processes. Urban planning must process, use and spread this diverse knowledge.

A comparison between the concepts of sustainability and planning reveals an important similarity: Both are constituted by a knowledge network. (cf. de Bruyn/Reuter 2011) In the case of urban planning, this network integrates technical, sociological, and cultural-historical knowledge. This leads to the question on how to plan the planning of sustainable districts: How can the network of knowledge be made accessible, how can it be used productively, and how can it be shared? Three areas seem relevant here: Consideration of the network structure of knowledge, integration of stakeholder knowledge into the planning process and the development of a low-threshold manner of knowledge transfer. In response to the structural change in the region, the city of Kaiserslautern is promoting the settlement of start-ups and high-tech companies. To increase the acceptance and the "utility value" of the planning results, the research project involved stakeholders from the start-up scene at an early planning stage by surveying their needs regarding business and urban space.

The needs of the start-ups were identified using, among other things, creative methods of spatial representation. As an example, Figure 21.1 shows the visualization of a current start-up company drawn by its founder.

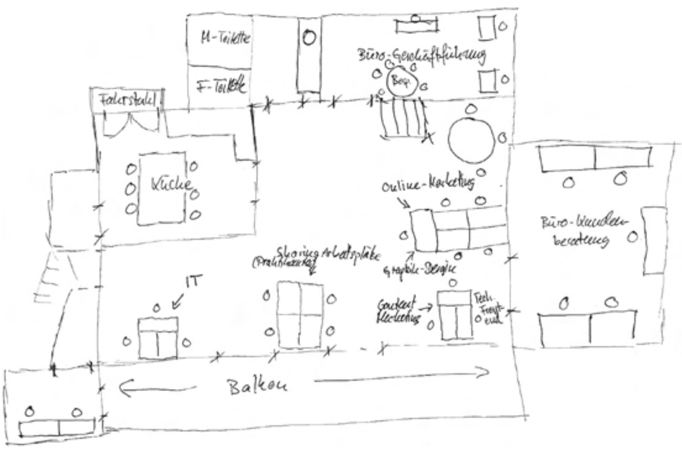

Figure 21.1: Floor plan drawn by stakeholders as part of social science survey.

The research uses a broad mix of social science methods. Empirical data on demographic change, energy, mobility, settlement space at state/city/neighbourhood level were used to evaluate the acceptance of planning parameters.

Qualitative research analysed the requirements and needs of start-up entrepreneurs relating to urban space and architecture. Qualitative guided interviews contributed to a deeper understanding of the lifeworld of the stakeholders. The research focused on questions about urban space, neighbourhood space, buildings, and mobility. At the neighbourhood level, the results show a tendency toward an urban mix of residential, commercial, gastronomic and public uses. From the respondents' point of view, neighbourhoods should be designed as inclusive for people of different ages and lifestyles. The respondents were also open to the location of technical facilities, such as energy production. In the area of buildings, there is evidence of approval for more communal and communication areas, informal meeting places and the flexible use of space depending on the situation.

Knowledge about sustainable urban planning is composed of interdisciplinary expertise and transdisciplinary stakeholder knowledge. For the development of planning parameters in the field of architecture, communication between different companies and spaces for rapid prototyping can be regarded as a key factor. Regarding the design of liveable neighbourhoods s questions about work-life balance, choice of location and on the ideal conception of urban corporate space became effective. The results of the survey form the basis for higher acceptance of design strategies within the target group, which activates the realization of sustainable design of the living environment. The results provide planners insights about the existence of multidimensional conflicts of objectives in the planning of urban neighbourhoods. These can be seen functionally in the direct working environment, on a neighbourhood scale, and in the idea of neighbourhood aesthetics and design. From this it can be deduced that architecture and urban planning consciously deal with these conflicting goals and approach or resolve them through design. The research activities make also evident that ideal demand planning requires cooperation with stakeholders. In this way, a continuous reconciliation between the needs of the actors and the design implementation can be achieved.

21.2.2 Involvement of Potential Users. Demand-Driven Planning of a Climate-Neutral Urban District

An important component of the research project is the integration of the various user groups into the planning process to achieve the greatest possible acceptance. In particular, the needs and expectations of future users (owners / tenants) were recorded and integrated into the overall concept (Demand analysis). For this purpose, stakeholders were discussed together with the city of Kaiserslautern and local representatives of the target groups were identified. These are analogous to the urban development framework plan: Science, health care, tradespeople, cultural workers, residents. As two particularly productive formats, the results of the population survey on the open day, as well as the surveys of employees from science and research, are presented here below.

Since a climate-neutral neighbourhood also requires the knowledge and actions of future users, it is important to analyse the needs of the different user groups. The knowledge about this enables a planning, which promotes climate-neutral behaviour under consideration of the needs. These findings form the basis for implementation, in terms of buildings, infrastructure and neighbourhoods. Studies on user behaviour and acceptance show that both aspects have a major influence on, for example, actual energy consumption or the demand for (climate-neutral) mobility services. Early involvement, motivation and information is therefore a key success factor for implementing a climate-neutral urban district. In practice, however, this is associated with two difficulties. On the one hand, the actual users are not known, so only the needs of target groups and thus potential future users can be ascertained, and on the other hand, the formal planning processes tend to stem from a top-down logic; participation in general does not reach the level of detail necessary for achieving the goals.[1]

The first example is the survey of employees in the field of science and research. Figure 21.2 shows the key needs identfied.

housing / living areas	living environment	mobility - infrastructure
Contents from the following areas Size, Number of Rooms, equipment, Ownership structure	**Contents from the following areas** max. distance to parks, max. distance to work, max. distance to food retail and cafe´s	**Contents from the following areas** Max. distance to public transport, sustainable mobility infrastructure, sharing economy

Figure 21.2: Central topics and results of the survey.

Since the neighbourhood as a climate protection showcase project has a high significance for all people in the city of Kaiserslautern, and citizens already living in Kaiserslautern also represent a future user group of the district, the citizens were given the opportunity to communicate their needs and wishes for the neighbourhood on the open day in the Pfaff-Areal. The following areas turned out to be particularly important (Figure 21.3).

These results were fed into the further planning process of the neighbourhood. In particular, the survey of the scientists led to valuable insights for the open space planning. (e. g. apartment size, neighbourhood design, desired housing type). It can be stated that by including potential target groups, a more precise determination of needs is possible. The insights of preferred forms of sustainable mobility for example was one reason for the bicycle friendly design of houses and traffic infrastructure. Based on this survey, further measures and infrastructure in the neighbourhood can be designed to promote climate-friendly behaviour (e. g. Smart Home, short distances to meet daily needs). Furthermore, extensive participation can lead to an increase in acceptance of the planning and the topics it conveys.

1 A detailed treatment of the topic Requirements for the planning of climate-neutral neighborhoods they Chapter I (Planning processes).

Figure 21.3: Thematic areas of citizen participation.

21.3 Contributions for knowledge Diffusion and Learning Under Developmement

21.3.1 Children's Climate Change Conferences

The Children's Climate Protection Conference is a concept developed by IfaS that includes a project day in a school class. This project day usually takes place on site in the schools, so that the participating children learn in their familiar environment and can directly apply what they have learned. In the EnStadt:Pfaff project, this method will also be used in the living lab (visitor centre) and up to 20 visitor classes will be introduced on site to the topic of climate protection in the neighbourhood.

The concept is based on the explanations of Schmid (2013). He analyses what is meant by knowledge and how it is passed on. The final step of the process was to examine how sustainable action emerges from this. If the information is processed by consciousness, this leads to knowledge. By linking the information with knowledge, skill is created. This can be transferred into action, if motivation exists (Figure 21.4).

The aim of the children's climate protection conference is to raise children's awareness about the responsible use of energy and natural resources. The focus is also on transforming the findings from the EnStadt:Pfaff living lab. To promote awareness of one's own possibilities for action, measures are demonstrated that bring about a reduction in CO_2 and achieve savings effects.

The children deal actively and practically with the problems, but also with the corresponding approaches to solving them. This should result in a lasting change in thinking and behaviour. The idea is that the children understand in a simple way what everyone can do for climate protection within the framework of children's cli-

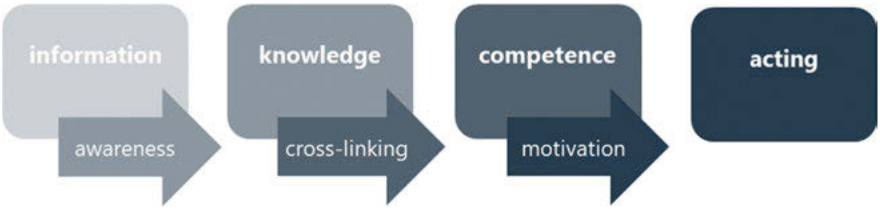

Figure 21.4: Knowledge transfer.
(Source: own representation based on (Schmid 2013))

mate protection conferences. By applying and passing on their knowledge independently, the children could transfer their motivation to their fellow human beings. In this way, there could be a chance that the groups of people reached process the information, create acceptance, which leads to changes in behaviour. Family members, friends and acquaintances might then pass on the information (at least partially) to other groups of people. This could reinforce the desired multiplier effect.

Climate protection as well as climate protection measures are integrated into lessons and can strengthen personal competencies (children's responsibility for their own actions). For example, they learn how to use energy consciously in everyday life and implement energy-saving behaviour. In addition, technical and methodological competencies are promoted through scientific work. An understanding of technology and logical thinking are also trained in a playful way.

First, system knowledge on the topic of climate change is built up. In the modules Energy Saving and Renewable Energies, consumption behaviour and the energy system are analysed, and it is conveyed how both could be improved. Finally, the children negotiate independently in the form of a conference which measures must be initiated or implemented for achieving a change (Figure 21.5).

The methodological approach makes it possible to transform the knowledge created, among other things in the EnStadt:Pfaff living lab, with an age-appropriate level and can thus promote conscious and sustainable future action. In this way, the project meets the requirement of addressing as many target groups as possible.

CLIMATE CHANGE	ENERGY-SAVING	RENEWABLE ENERGIES	THE CONFERENCE
System knowledge Knowledge of what it is and how it works	**Target knowledge** Knowledge of what should be and what should not be		**Transformation knowledge** Knowledge of how to get from the current state to the target state

Figure 21.5: Central aspects of education for sustainable development.

21.3.2 Making the Living Lab Physical – The Reallabor Center and Smart District Workshop

The interest, ability, and willingness of the different actors (investors, residents, employees, planners, administration, politics, companies, public, etc.) to deal with the necessary changes in climate neutral neighborhoods (Pfaff-Quartier, other neighborhoods in Kaiserslautern, neighborhoods in general), to accept them and to implement them in their own actions is crucial for the successful transformation of the neighborhoods and cities to climate neutrality. Still, how the content could be (better) communicated to be adopted by stakeholders needs to be better understood to make the transformation successful.

A living lab typically provides a physical space in which the various actors can meet and work together and in which the neighborhood and all its components can be understood and technically controlled. As a lighthouse project, there is also the aim to make the concepts and implemented measures visible and explain them to external interested parties (interested laypersons, trade visitors, media, etc.). This is a particular challenge due to the large number of individual measures, the components that are often not visible (e.g. the energy networks), but also because the Pfaff Quarter is only at the beginning of an approximately 12-year development phase.

For this reason, the realization of the Living Lab Center is envisaged, which will provide the physical space for the provision of the afore-mentioned functions.

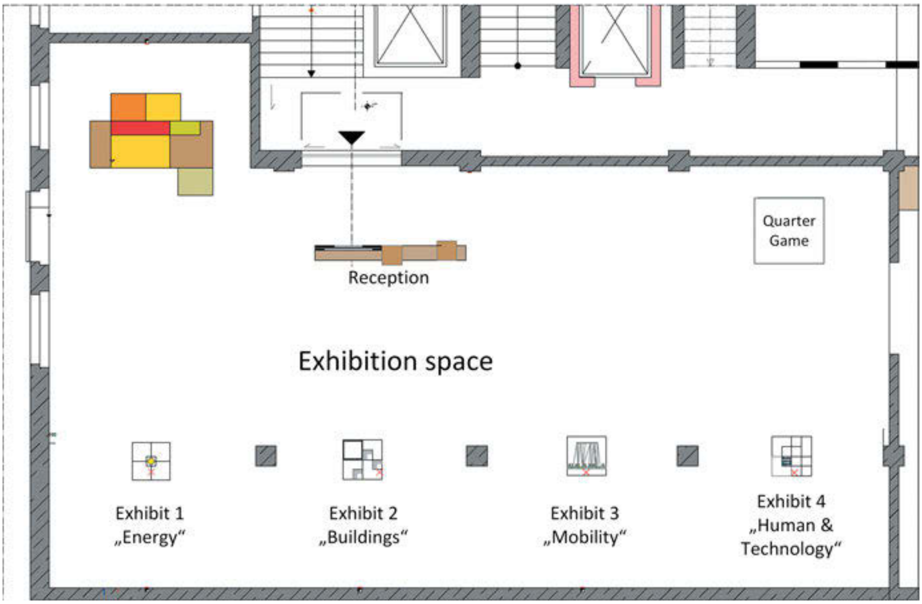

Figure 21.6: Design study for the layout of the exhibition area (left floor plan, right section lounge).

To meet the different requirements in terms of target groups and functionalities, the Living Lab Center provides a visitor center with exhibition (for details cf. chapter 21.4.1). For interested laypersons and professional visitors from Kaiserslautern, Germany and abroad, the concepts pursued, technologies implemented and research carried out in the Pfaff Quarter are presented in a permanent exhibition in a generally comprehensible, interactive and innovative manner in line with their forward-looking character, among other things using virtual augmented reality representations. The exhibition and entrance area as well as a lecture and meeting room form the central area of the Living Lab Center.

Another part of the Living Lab Center is a district workshop. This workshop aims being a place to communicate and with citizens about the project, project ideas, and solutions. Moreover, it should be a place where one can work together to create new ideas, prototypes, and solutions that support the climate neutrality. The focus is on digital solutions in the workshop. Part of the whole smart district workshop concept is a strong attitude towards citizens and further stakeholders, and though we face the challenge of not being at the Pfaff area for a long time due to construction work and further issues, we considered alternative ways of communicating project results with the public, and to offer ways of how to include people outside the project and with this to connect better with them already. To facilitate communication, we shift towards a mobile character of the district workshop and concentrated on producing videos about our results that we share on a Youtube[2] channel. Second, events such as our yearly PFAFF HACK[3] is also part of the district concept, and we could already include more than 100 participants that developed digital prototypes in those events. While the first hackathon in 2018 concentrated more on general concepts how digital solutions can have a positive influence on climate-friendly behavior of citizens, the following ones concentrated more and more on concrete prototypical solutions. In 24-hour-events, several teams developed software prototypes in mobility, neighborhood support, or energy. Ideas of such prototypes influences further directions in the project to develop concepts for the digital district ecosystem.

21.3.3 Exhibits in Transformation – The Exhibition as a Medium for Transformation

The Theory of Social Practice attributes central importance to different civil society actors in the sustainable transformation of socio-technical systems. Their local knowledge in the context of community action enables democratic social change. (Hargreaves/Haxeltine/Longhurst et al. 2011, Mulugetta/Jackson/Van Der Horst 2010) The success of projects like EnStadt:Pfaff is therefore linked to the fact that stakeholders learn to understand and ac-

2 https://www.youtube.com/channel/UCK8LjvcvaCHBF-voo0qcqqA.
3 https://pfaffhack.iese.de/de/.

cept the contents of socio-technical change. As complex media for presentation (Scholze 2004), exhibitions are able to convey scientific and technical content and processes. Accordingly, part of the "EnStadt:Pfaff" project is a participatory and mobile exhibition, designed to communicate the research content and innovations on the Pfaff site. It contains exhibits which as boundary objects, epistemic objects and as technical objects at the same time represent knowledge stored in artefacts at a specific cultural location. As such the exhibits represent communicative connections between science, technology and stakeholder knowledge. (Ewenstein/Whyte 2009)

The development of the exhibition reflects an inter- and transdisciplinary process of co-production, making the exhibition participatory. This can be exemplified in the development of the exhibition concept. In a series of different methodological formats, such as design research, design thinking, individual and group interviews, benchmark analyses and workshop formats, various consortium partners from the city administration, institutes, universities and local companies were involved. A cooperation with the agency GROSSE8 from Cologne made it possible to check the implementation of theoretical contents in a real-world context. This phase resulted in a detailed, standardised and representative exhibition concept that serves as the basis for the public tenders. The concept summarises the context, basic principles for the identity of the Pfaff neigbourhood, design concept, target groups and personas, requirements for the exhibition space as well as data on the exhibits and content from the topics of energy, mobility, buildings and humans and technology. The main topics and a basic layout of the exhibition are shown in Figures 21.6 and 21.7.

Therefore, the compatibility/interoperability of analogue exhibition furniture with augmented reality technology (AR) is central. Thus, analogue exhibits can be expanded in terms of content through digital technology, such as the graphic representation of energy currents on a handheld device, in order to present the association with the complex, invisible technology in the background of the analogue neighbourhood.

The aim of the exhibition is to let visitors experience which project components contribute to climate neutrality in the Pfaff neighbourhood and how. To this end, the planned technical innovations of the development process are made tangible and experienceable through the exhibits, to which the linking of analogue elements and augmented reality technology contributes significantly. This allows the exhibition concept to be experienced interactively in the Living Lab Center and makes the research focus of the project and the solutions envisaged in the Pfaff Neighbourhood in the field of climate-neutral neighbourhoods visible and explains them. Due to the mobile design principle, the exhibits can be relocated so that knowledge can be imparted in different educational contexts, such as in school classes. The high proportion of virtual 3D elements also contributes to the mobility of the exhibition. Since the prototype exhibition was created entirely with computer-assisted design programmes (CAD), a completely virtual exhibition is also conceivable in the future. This is illustrated in Figures 21.8, 21.9, and 21.10.

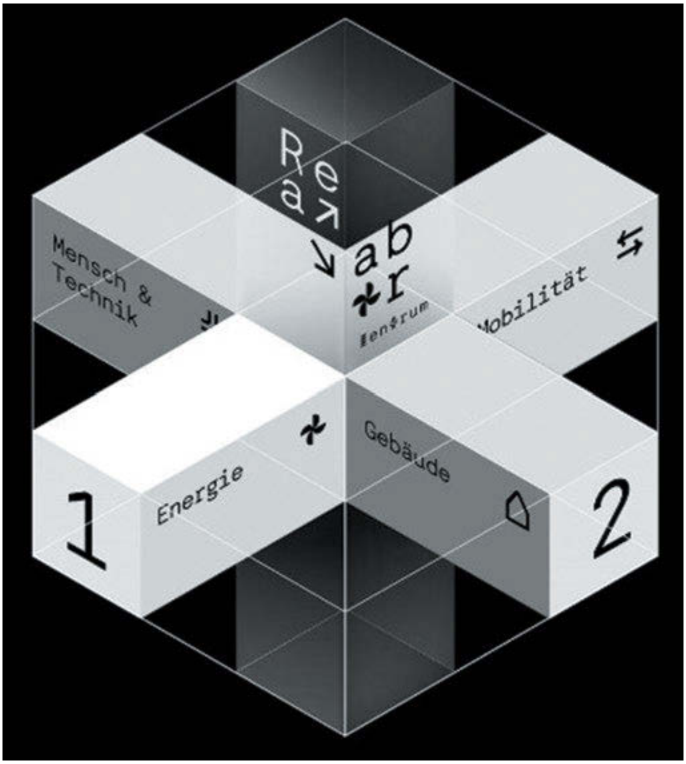

Figure 21.7: Draft of the presentation of the Living Lab exhibition with the 4 topics: energy, buildings, mobility, and humans and technology.

Guided tours of the exhibition and visitor workshops facilitated by professional staff allow for a high pedagogical quality and enable public participation and scientific citizenship. (Bandelli/Konijn 2015) In this way, the transformation is driven beyond the boundaries of the exhibition and the research project. Ideally, a "community-level action" (Mulugetta/Jackson/Van der Horst 2010) is created, whereby the socio-technical changes addressed are accepted, appropriated and adopted in everyday life.

21.3.4 Quarter Game

In addition to the activities of those directly involved in the Enstadt:Pfaff project, it is also crucial for the achievement of a sustainable neighbourhood that investment decisions made by the private sector in the neighbourhood are geared toward sustainability and that sustainable behaviours are established among the people who populate the neighbourhood.

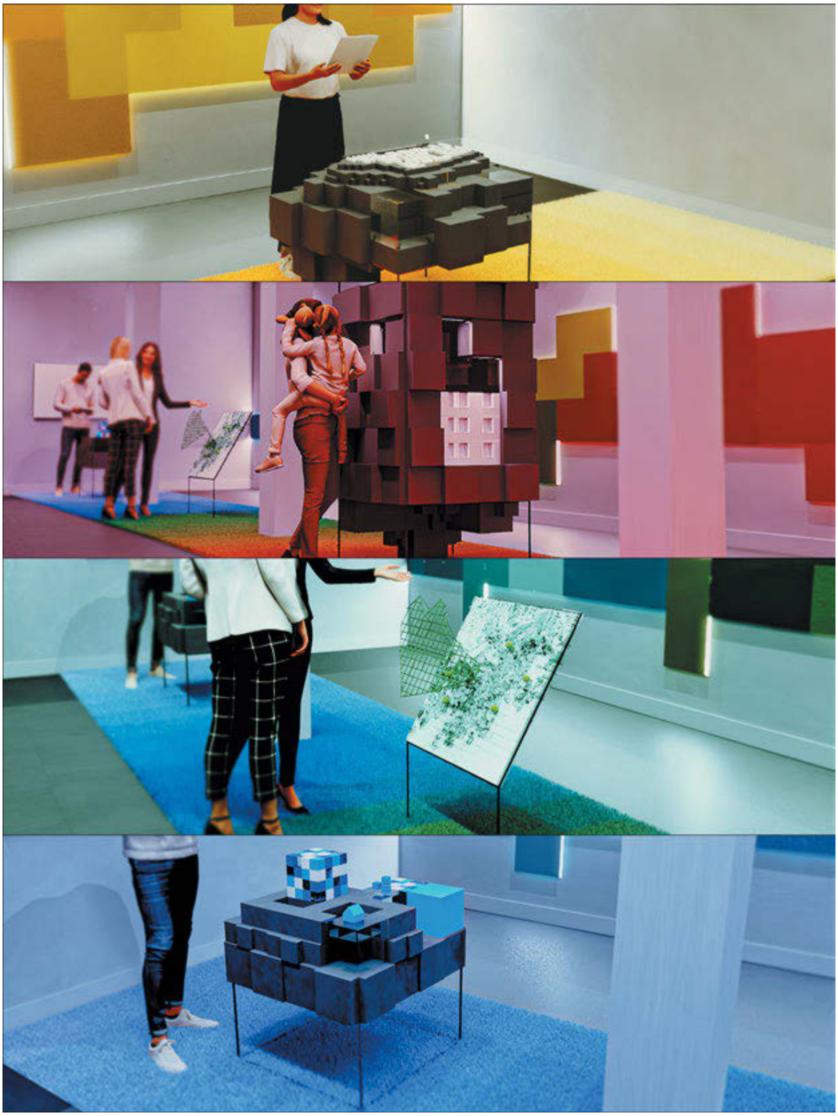

Figure 21.8: Renderings of the designs of the four exhibits.

Accordingly, private and private-sector actors have to be able to contribute to a climate-neutral and sustainable neighbourhood through their actions and businesses. Ideally, they will be enabled to grasp the established concepts and how their own actions (investment decisions, etc.) relate to them.

A contribution to this is made by the interactive neighbourhood game as an exhibit of the exhibition. In this game, visitors find themselves in the role of neighbourhood planners and investors. By making clever decisions in the game, a living neighbourhood

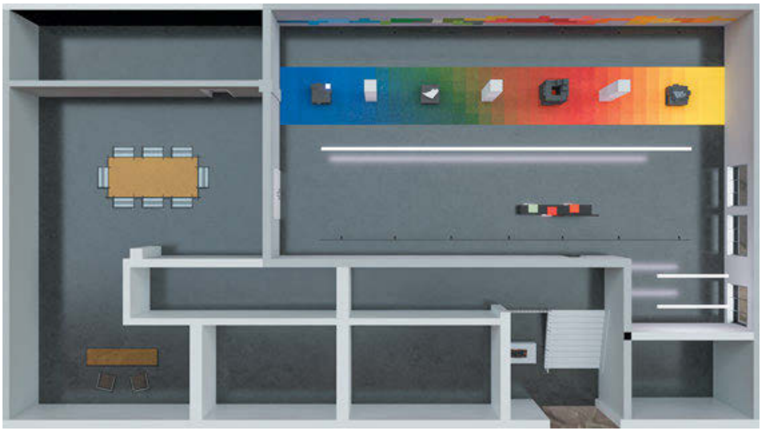

Figure 21.9: Prototype of the rooms of the Pfaff Living Lab with exhibition space, meeting room and neighbourhood workshop as computer-generated imagery.

Figure 21.10: Prototype of the exhibition space as computer generated imagery.

is to be realized that takes into account all sectors as well as the partial aspects pursued in the Living Lab – energy supply, mobility, buildings, digitalization and social aspects are to be maximized in a balanced manner with regard to climate neutrality, satisfaction and economy.

For this to be achieved, it is necessary to integrate a model representation of neighbourhood development into such an exhibit, which forms the basis for game behaviour as an underlying quantitative game mechanic. (Hunicke/Leblanc/Zubek 2004, Schell 2008, Suter/Kocher/Bauer 2018) For learning success via such simulations, it is crucial to depict the mapped relationships in a realistic and plausible way. (Blötz 2015a)

In order to come as close as possible to this goal, a complex participatory modelling process was initiated in which the system-dynamic interdependencies that come into play in the development of the neighbourhood are worked out in an interdisciplinary manner with the experts of the research project. In the form of collaboratively developed causal loop diagrams as part of the system dynamics methodology, the transformation process is first qualitatively modelled. (Maani/Cavana 2010, Sterman 2000) The subsequent transformation into a quantitative stock flow model creates a basis that could already be used as an independent business game at this stage of development. (Blötz 2015b)

However, the business game format does not seem to be suitable for an exhibit in an exhibition due to the expected length of stay and the composition of the group of players. Instead, it is important to choose an attractive interactive medium that encourages voluntary consumption and supports an experimental learning process that promotes and maintains motivation. Serious games represent a promising and contemporary way to achieve this. (Abt 1975, Dörner/Göbel/Effelsberg et al. 2016)

Therefore, a design for an attractive interactive digital casual serious game was developed with game development students of the University of Applied Sciences Offenburg, which meets the requirements of an exhibition exhibit on the one hand and a staging that does not abbreviate the complexity of the neighbourhood transformation event on the other hand in the best possible way.

Figure 21.11: Prototypical implementation of a design element of the game by students at Offenburg University of Applied Sciences.

With a Monopoly-like game principle, the game is based on a simple and proven gameplay. Players gradually shape the neighbourhood along a game route in a 3D game world by making decisions on the use, design, and equipment of buildings. The exhibit is designed as an interactive touch table.

Through the neighbourhood game, users of the neighbourhood can thus acquire systemic transformation knowledge via an attractive learning medium and are thus enabled to better contribute to a sustainable quarter development through their own actions.

21.4 Conclusion

Transfer of knowledge is an essential element for succeeding in a transformation as in the Pfaff quarter in Kaiserslautern. Especially the Living Lab Center is of great importance for the implementation phase of the neighbourhood and for the communication and multiplication of the project results with the purpose of transfer to other neighbourhoods in Kaiserslautern as well as in other cities in Germany and also internationally.

Future evaluation and impact assessment will be expected to provide insights to which extent the aimed goals for learning and knowledge transfer have been reached and which major take-away lessons visitors and auditory might express after having divided into the learning offers of the EnStadt:Pfaff quarter.

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Martin Eckhard, Torben Stührmann, David Sauss

22 QUARREE100 – Resilient, Integrated, System-Serving and Sustainable Energy Supply Systems in Existing Urban Quarters in the Context of Regional Structural Processes

Summary: QUARREE100 is an innovative research project with associated implementation that takes on the challenge of establishing an integrated, sustainable energy supply in the heterogeneous existing quarter "Rüsdorfer Kamp" in Heide. The quarter represents a variety of urban structures, which significantly increases the complexity, but also represents a high chance of transferability.

On the basis of extensive modelling and research work, an energy concept has been developed that can meet the complex requirements. However, the high investment costs are a challenge for implementation, which are currently difficult to present to potential investors on the basis of classic economic evaluations in comparison with fossil energies. In addition, the high investment costs result in long-term amortisation periods for affordable heat in an energy system in transition, which also leads to further uncertainties on the investment side.

The project is also integrated into other strategic processes of the city and the region, which on the one hand also promote urban development and solutions for an integrated energy transition in the region, which then also involves local industry.

22.1 Introduction

The challenges for a climate-neutral building stock in our towns and villages are immense. We often have heterogeneously developed structures in which, for example, renovated and unrenovated buildings coexist with housing and commerce, local architecture and old energy infrastructures, and especially citizens with very different economic possibilities. This situation is also reflected in the 20-hectare "Rüsdorfer Kamp" quarter in Heide, where around 600 people live and work. In addition, Heide has Germany's most densely built-up area with wind power and turbines regularly have to be curtailed due to a lack of grid capacity.

Martin Eckhard, Entwicklungsagentur Region Heide, Germany
Torben Stührmann, University Bremen, Resiliente Energiesysteme, Germany
David Sauss, Steinbeis Innovationszentrum energieplus, Germany

https://doi.org/10.1515/9783110777567-022

The goal of QUARREE100 in "Rüsdorfer Kamp" is to use as much renewable energy as possible from the immediate surroundings and to support the upstream energy system. In addition to the technical aspects, QUARREE100 also integrates the local citizens through active participation and is dedicated to economic models so that the new system is economically viable in the long term.

The QUARREE100[1] project (since 2017) is integrated into various other measures and levels of action in the city of Heide and in the Heide region and is thus embedded in an integrated urban development concept (2009), in an urban neighbourhood development concept (2016), an energy-related neighbourhood concept (2016), a redevelopment management (since 2019), urban development funding (since 2020), a regional urban-rural concept (since 2013) and the regional project initiative "ENTREE100 – Energy Transformation of Renewable Energies towards 100%" (since 2015).

22.2 The Quarter

The town of Heide is situated not far from the North Sea and the river Eider in a landscape of geest and marshland. It is a recognised tourist destination and, as the district town of Dithmarschen, forms the economic centre of the southern west coast of Schleswig-Holstein. As a medium-sized centre, it provides services to the local area (about 36,500 inhabitants) and to the central area (about 70,000 inhabitants). The city itself has about 21,100 inhabitants. Climate protection, energy efficiency and renewable energies are an important field of development in the city and region of Heide, led by the ENTREE100 project initiative.

The Rüsdorfer Kamp quarter is located directly at the railway station near the centre in the south-east of Heide, but the railway lines form barriers to inner-city areas. Bordered by a railway line in the west, Hamburger Straße (B203) in the north, Hans- Böckler-Straße in the east and Berliner Straße in the south, the area, which is characterised by residential buildings mainly from the 1950s – 1960s and commercial enterprises, covers about 20 hectares. Heide District Hall is in the immediate vicinity, the walk to the market square takes about 15 minutes and the University of Applied Sciences is also close by.

The quarter settlement structure of the Rüsdorfer Kamp offers ideal conditions to realise various energy concepts in an exemplary manner and thus take on a lighthouse function. About two-thirds of it consists of single-family houses, some of them historic old buildings, as well as terraced house halves. One third of the housing estate is made up of multi-family houses. In addition to some commercially used areas, the quarter also includes two large, undeveloped green spaces. The northern open space covers about 1.6 hectares, the southern area almost 1.3 hectares ("Im Grund" and "Neue Mitte").

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1 For more information on the project, all project partners and the newsletter, please visit quarree100.de.

On these areas, small-scale, inner-city mixed-use urban quarters are to be created that are perceived by their residents as suitable for everyday life and of high quality.

The quarter should also become attractive through diversity, especially for young families, new professionals and students of the Heider University of Applied Sciences Westküste, who currently rarely live in the quarter despite its proximity to the university. The mix of different housing typologies and forms combined with climate-friendly construction, topics such as resilient urbanism and the early involvement of residents should make the quarter sustainably attractive.

In the Heide region and in the entire state of Schleswig-Holstein, the energy transition is already well advanced. However, due to a lack of grid expansion and flexibility options, wind turbines have to be shut down more and more frequently. Therefore, holistic concepts for the flexible integration of renewable electricity into the energy supply are urgently needed for the success and further rapid implementation of the energy transition. QUARREE100 is a lighthouse project in the Rüsdorfer Kamp quarter with its heterogeneous settlement structure, whose overall energy concept can be transferred to other regions nationwide.

The area is to be significantly upgraded in terms of energy, urban climate and social value through the measures to be implemented. The project focuses on the implementation of a cellular, multi-modal and resilient energy production and supply within the neighbourhood, which includes both the existing and new buildings in the implementation and not only the heat supply, but also the power supply and mobility. In addition to the goal of a high energy self-sufficiency share, system serviceability for the upstream electricity grid is to be realised in particular through the implementation of highly innovative flexibilisation options, storage and conversion technologies. The proximity to the West Coast Industrial Park and the Heide refinery also provides options for an energy connection to industry, the inclusion of which is inevitable for a holistically conceived energy concept.

22.3 Overall Objective of the QUARREE100 Project

The aim is to develop a cellular and efficient electricity, heat generation and supply concept based on the subsidiarity principle. -supply concept according to the subsidiarity principle, which takes into account both centralised and decentralised renewable energy sources and relieves the regional electricity grid through intelligent control at quarter level. Through the interplay of different renewable energy sources, conversion technologies and storage, flexibilities and services for the surrounding energy system are generated in the quarter, while at the same time electricity from renewable sources is fully utilised.

If we look at the heating sector, the balance between heat supply and heat demand plays an essential role for climate protection and a successful energy transition.

A particular focus of QUARREE100 is therefore on a sustainable heat supply in the quarter, whereby a highly efficient and at the same time resilient heating concept is created on the basis of large heat pumps and a local heating network, combined heat and power plants in combination with small-scale hydrogen production and local PV electricity, into which both new and existing buildings can be integrated.

With regard to electricity, the approach of maximum electrification with the help of photovoltaic electricity generated in the quarter is being pursued in order to achieve a high level of efficiency. The PV roofs will not be aligned according to demand, but rather according to maximisation in the sense of a system-serving self-sufficiency. The fundamental goal is that the quarter should place as little burden as possible on the upstream grids, but should be able to provide as many services as possible, especially with regard to storage and flexible loads. Electricity surpluses will be stored electrochemically in central battery storage units and thermally or chemically in heat and gas storage units (P2G).

In addition, the potential contributions of hybrid mobility for individual and public transport, for example, will also be examined and implemented in exemplary solutions. For this purpose, technical-systemic concepts for a “filling station of the future” with the media hydrogen, methane and electricity have been developed and will be demonstrated as a concrete implementation of an “energy hub”.

In the context of the energy supply of the selected quarter, both the principle of “sector coupling” and the “cascading use” of the generated/sourced electricity are being developed and tested. Thus, for extended security of supply and flexibility, the heat pumps can also be fed with (renewable) natural gas/hydrogen if there is insufficient electricity generation in the quarter. The resilient design of the energy supply, i.e. securing the supply even under extreme situations and uncertainty, can certainly conflict with a purely efficient solution, which is why an optimal balance between efficiency and supply security is being investigated and implemented in the project. The basically cellular design of the quarter requires a maximum of system efficiency for the surrounding electricity grid, which is realised as needed through flexible load shifting and storage (thermal, electrochemical, chemical) and intelligent control of the quarter’s internal systems and consumers. In principle, the approach is that as many aspects of the energy supply as possible are controlled in the quarter and that coupling with the upstream grid only takes place in bottleneck and emergency situations. This also applies to data management and processing, so that basic concepts for encapsulating information processing are also being developed in order to derive transferable specifications for implementation in quarters.

The project will develop new technologies in the field of storage and conversion as well as further develop or test existing technologies. The technologies to be selected will also be tested for their suitability in a system analysis with the help of models and simulations in various system configurations and a transferable toolbox for the modelling and planning of quarter energy concepts with high system efficiency will be developed.

This determination of the economically, ecologically and technically optimal variant with the help of simulation models for a trend-setting overall concept of a quarter with “nearly zero emission buildings” was supported by a participatory dialogue process initiated at an early stage for the weighing of goals and conflicting goals, especially with regard to ecological effects, economic burden sharing and efficiency as well as the role of self-sufficiency, security of supply and resilience.

In particular, the economic and regulatory feasibility of the developed concept has been and will be comprehensively analysed during the project. Likewise, the emission reduction potentials of the envisaged heat and electricity concepts as well as their other ecological effects play an essential role. At the implementation level and to ensure a high level of acceptance, civil society actors are integrated into the design of the energy concept from the very beginning by means of citizens’ events and surveys. Even before the application was submitted, citizens’ information evenings were held in the city of Heide to discuss concepts for modernising and upgrading the Rüsdorfer Kamp quarter. This was followed up immediately. The citizens are to play a responsible role in this, not least because they are partly an active part of the concept in the implementation phase. Therefore, the participatory element does not end in the reception of information alone, but in their involvement in decision-making processes.

The project objective can therefore only be implemented with a quality assurance concept for the buildings and the technical building equipment, the generation and storage facilities, and other facilities in the planning, construction and commissioning phases and subsequent success control via monitoring. A corresponding monitoring concept will be developed in the course of the project and can be applied in the realisation phase. The integration of systemic properties such as resilience and system efficiency in particular requires a high degree of basic research for monitoring complex development goals.

22.4 The Energy System

The energy system in the “Rüsdorfer Kamp” of the future will be very much characterised by a high degree of flexibility in both energy generation and supply.

The special focus is on sustainable heat supply, which is to be made available to households and commercial enterprises via a new local heating network.

In a cascading system, the required heat is first generated by large-scale air-source heat pumps and using the PV electricity produced in the quarter. If there is a surplus of electricity, it is first temporarily stored in a battery and in the next stage made available to an electrolyser for the production of hydrogen. In the process, the PV electricity in the quarter is fed to the energy centre with the aforementioned aggregates via a unidirectional operating grid on the electricity side from the solar modules.

If the PV electricity in the quarter is not sufficient, the necessary electricity is generated by a CHP unit using natural gas (later hydrogen) and the heat produced is also made available to the heating network. A heat storage system, in turn, serves as a necessary load buffer and provides sufficient heat in the event of a possible blackout,

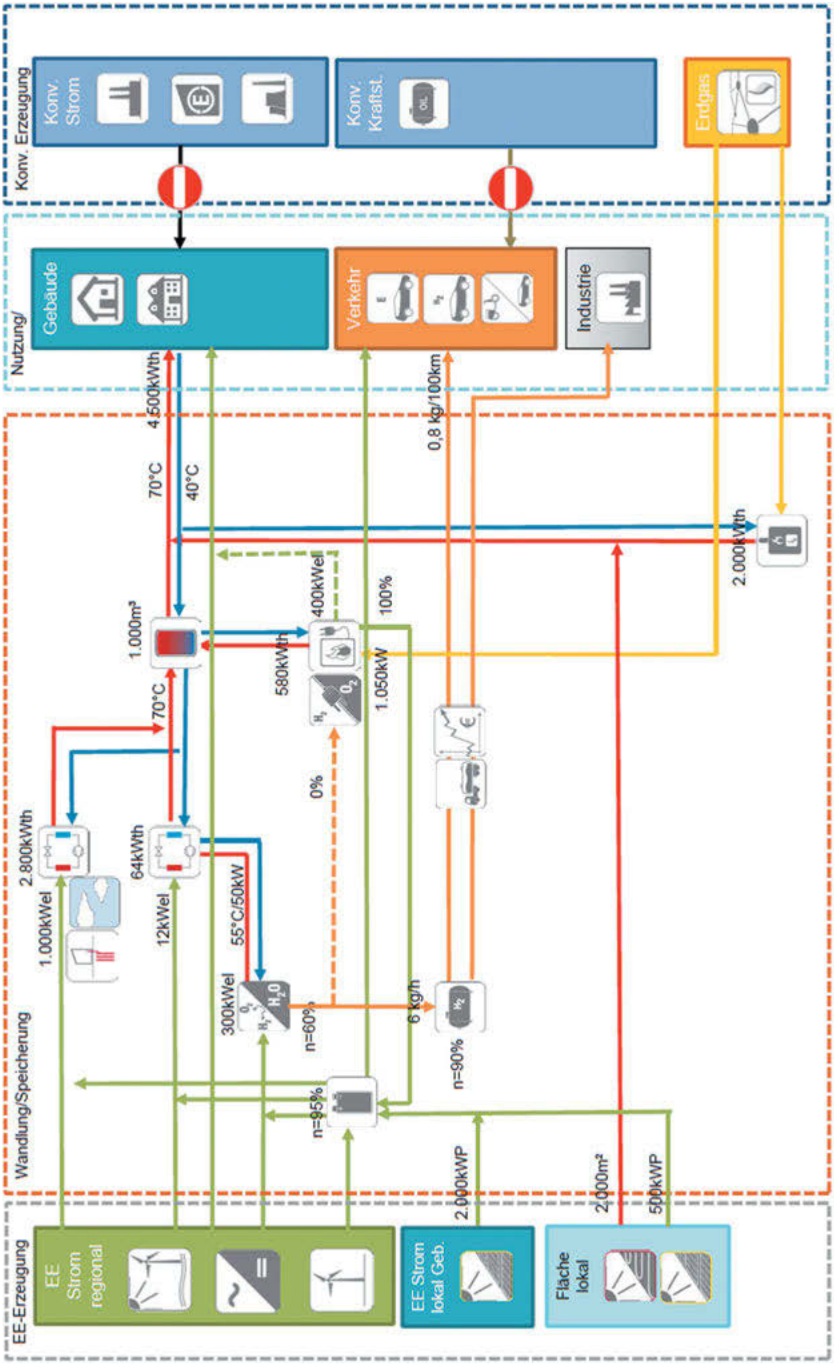

Figure 22.1: QUARREE100 energy system.

and is thus an important component for the efficient integration of fluctuating renewable energies.

A natural gas boiler is also available as a redundancy system for downtimes (malfunction/maintenance) or in the event of a dark period lasting several days with very cold outside temperatures.

The hydrogen is to be made available for mobility, provided it does not have to be used for the CHP.

One challenge today is the very different energy requirements depending on the building and the uncertainty as to when individual buildings will be renovated to make them more energy efficient. For this reason, the heating system will be designed in such a way that a supply temperature of 70° C can be used to supply all connected users. There is also the possibility that the two planned new building areas “Im Grund” and “Neue Mitte” in particular will receive a lower flow temperature through a separate heating line from the energy centre or connected to the return flow. The system will be designed in such a way that it can be easily adapted for future renovations or new developments.

By connecting the consumption sectors of electricity, heat and mobility, a new, networked energy supply system is created that meets the requirements of a sustainable energy system. The focus here is in particular on a system-serving mode of operation that relieves both the local and the upstream power grid and thus facilitates the integration of fluctuating renewable energies. This system is highly resilient, i.e. able to withstand even sudden unexpected changes, and can supply the quarter reliably and provide flexibility services.

On the basis of such an integrated and networked energy supply system, the models show that an almost climate-neutral, CO2-free energy supply in existing quarters is possible in the future, although the heating sector will probably still have to be supported by gas (e.g. hydrogen or synthetic methane) on some cold days.

22.5 Business Models and Acceptance

Economically, however, this system must also be sustainable. It is therefore the clear goal of QUARREE100 to offer customers energy at compatible and stable prices in the future through innovative business models. There is a further challenge here, as energy sector coupling has not yet been adequately reflected in the regulatory framework. Here, too, simulated QUARREE100 scenarios. Among other things, the study examines how a CO2 price or far-reaching changes to the Renewable Energy Sources Act (EEG) would affect the economic viability of the various energy supply concepts.

This view into the regulatory crystal ball is challenging, but it seems possible to set the necessary incentives so that economic operation over a depreciation period of 20 years can become probable. For potential investors in such a sustainable, energetic quarter supply, this uncertainty, especially on the temporal level – when which legal changes will come – is a major obstacle. QUARREE100 has therefore already actively developed regulatory implementation proposals based on the modelling results.

For local citizens, the focus is on affordability, i.e. future energy costs, and possible structural changes in the quarter. In the run-up to QUARREE100, the wishes of many citizens in the quarter were already taken into account through joint workshops and events as part of an urban planning concept. The general quality of life is important to them, e.g. through the preservation of green spaces or the reduction of through traffic. QUARREE100 has taken up this dialogue with citizens and regularly engages in dialogue with them in very different formats. For this purpose, an information container serves as a central contact point, workshops, a neighbourhood festival, neighbourhood tours, a regular newsletter sent by post, but especially bilateral "kitchen talks" where individual citizens are visited at home.

The presence on site is very important, because especially in the research and planning phase of the project, where a lot of research work that is not directly visible to the citizens, such as modelling, is carried out, it can be shown and explained.

22.6 Implementation

The actual, real implementation on site is of particular importance for all those involved. It is the declared aim of QUARREE100 to demonstrate such a sustainable energy system in the "Rüsdorfer Kamp". Based on the modelling, the energy concept presented above has been developed, which is currently being worked out in detail and transferred to the planning phases.

This is also accompanied by the urban planning for the necessary energy centre. A suitable urban site has been identified and the necessary development plan is in the process of being drawn up.

A particular challenge is that an investor and operator must be involved in the implementation of this task, especially in view of the high economic risk. This search for an operator and investor is proving to be very difficult and time-consuming. At the moment, the city of Heide is planning to establish its own heat supply company and at the same time various business enterprises have expressed their interest in the project within the framework of an expression of interest procedure, which, however, has not yet been concluded.

At the same time, QUARREE100 is developing a model construction kit on the research side. This will make it much easier for other municipalities and cities to determine the options for designing their own sustainable quarters. In this way, regional specifics, whether neighbourhood structure or climatic conditions, can be taken into account more easily. QUARREE100 wants to actively contribute to making the research results and experiences from Heide transferable.

22.7 Accompanying Measures

QUARREE100 is integrated into a wide range of other activities and projects in the region.

22.7.1 Integrated Urban Development Concept

The Integrated Urban Development Concept (IUDC) (Böhlke/Leue/Lösse et al. 2010) which the city of Heide drew up in 2009, sets out the goals and guidelines for sustainable, future-oriented urban development and develops a conceptual and long-term overall perspective of urban development. The IUDC is formulated as a flexible and informal planning instrument and is continuously updated.

In the IUDC, the preparation of an urban development concept and initial proposals were already formulated for Rüsdorfer Kamp. The focus here is on improved land use, especially in the context of "family living".

22.7.2 Urban Development Concept for the Quarter

Based on the recommendations of the IUDC, it was possible to develop an urban development concept for the quarter which was carried out in 2015/2018 in parallel to the energy-related neighbourhood concept for Rüsdorfer Kamp.

Rüsdorfer Kamp is a mixed-use quarter consisting of a compatible coexistence of living, working and trading. These three functions are included in the overarching concept, supplemented by a mission statement, diverse proposals for fields of action and measures, and the coordinated interaction of large and small property owners, and forms an inclusive framework for action for integrated quarter development in Rüsdorfer Kamp.

22.7.3 Energetic Neighbourhood Concept

The energetic neighbourhood concept (Bielenberg/Wortmann/Knitter 2018) was developed in 2016–2018 together with the urban development of the quarter and worked out cooperatively as part of a coordinated overall planning process.

The aim of the energetic neighbourhood concept was to identify basic measures for the energetic and economically optimised refurbishment of the existing buildings in combination with a few new building projects to be constructed in a climate-friendly way and a sustainable, heat and energy supply planning.

Within the framework of the concept, a large number of measures were identified that represent options for action both at the municipal level and at the level of private owners. From these results, it can be concluded for energy-related renovation that renovation measures on the building envelope alone will not be sufficient to achieve the climate protection goals in the medium to long term. The use of renewable energies is absolutely necessary – especially with the construction and installation of heating networks, which in turn was transferred to the modelling of QUARREE100.

22.7.4 Remediation Management

In addition to the overarching QUARREE100 energy concept and building on the energetic neighbourhood concept for Rüsdorfer Kamp, since 2020 the energy remediation management has been focusing directly on individual citizens in the quarter. (Bitzinger 2020) The goal is to give all citizens of the quarter the opportunity to receive high-quality energy advice for their building. The owners are advised on all relevant measures for their house.

22.7.5 Urban Development Funding

Building on a positive decision by the municipal bodies on the Rüsdorfer Kamp quarter development concept and its continuation as an urban redevelopment measure, a step-by-step development and implementation process that will last several years was then launched in 2019.

The necessary preliminary investigation is currently being carried out within the framework of urban development funding (Bitzinger/Pump-Uhlmann 2021) and the fields of action are being identified and prioritised, taking into account the previous concepts and on the basis of their significance and intended effect for the quarter. The focus here is on transferring the concepts into concrete urban development implementation.

22.7.6 Urban-Rural Cooperation

The town of Heide and the eleven municipalities of Hemmingstedt, Lieth, Lohe-Rickelshof, Neuenkirchen, Norderwöhrden, Nordhastedt, Ostrohe, Stelle-Wittenwurth, Weddingstedt, Wesseln and Wöhrden which belong to the KLG Heider Umland office, have launched a cooperation model that has received nationwide attention with their town-country cooperation.

The existing urban-surrounding area concept (SUK) (Burmeister/Schwender/Schmidt-Gutzat et al. 2020) of the twelve participating municipalities serves as a conceptual basis for the inter-municipal cooperation of the city of Heide and the eleven surrounding municipalities in a medium-term forecast up to the year 2030, in order to successfully meet the growing challenges of demographic, economic structural and ecological change. The QUARREE100 project is thus also a flagship project for the region.

Through innovative projects, such as QUARREE100, and attractive framework conditions, it is important to establish new application technologies within the region, to attract skilled workers to the region and to bind existing potential to the region. Furthermore, the SUK will further develop the infrastructural conditions, increase the potential for internal development and strengthen residential and transport development and the provision of public services, including the medium-sized centre of Heide.

The successfully implemented projects and initiated network structures are based on the successful establishment of adequate organisational framework conditions. First and foremost is the implementation of the Development Agency Region Heide AöR, which also functions as the SUK office, by the twelve participating municipalities.

22.7.7 ENTREE100

ENTREE100 (Burmeister/Träger/Haalck 2021) is a project initiative and an innovation-oriented network of the Heide region with the aim of finding renewable energy projects and suitable project partners and initiating the first-time implementation in the region.

The aim is to demonstrate an integrated energy transition in the Heide region. Projects are to be implemented for the first time and integrated 100% into the energy or overall economic system. In this way, the projects are to be further developed so that they are scalable in the Heide region and transferable to other locations.

ENTREE100 serves as a catalyst for merging project ideas and partners. As a superordinate structure, ENTREE100 links the various research projects in the region, which in addition to QUARREE100 include the real laboratory WESTKÜSTE100, KEROSyN100, SYSTOGEN100 and HYPLANT100, to form an integrated energy system for the region. (Eckhard 2020)

In order to achieve this goal, ENTREE100 is also building an international network of different sectors (manufacturing and service industries, science, NGOs, investors and politics) in order to develop project ideas and bring together project partners.

The aim is also to make the Heide region interesting, especially nationally but also internationally, for attracting companies and increasing regional added value, with a particular focus on the regionally available resources of green energy.

22.8 Final Consideration

QUARREE100 is a central component of an overarching portfolio of research and implementation measures in the region; with its focus on the sustainable transformation of the building stock, it makes an important contribution to strengthening the quarter, the city and the region.

Figure 22.2: Integrated energy system for the Heide region.

QUARREE100 itself already shows how research can be transferred. From extensive research with diverse modelling, technical developments, regulatory considerations and participatory methods, all partners in the alliance have developed a technical implementation concept that can fulfil the complex goals of sustainability, resilience and cellular, regional solutions for the integrated energy transition.

Challenging for the implementation are the economic risks still associated with this system. Such a system is a long-term investment in the future that still has to compete with fossil energies.

However, it is also evident that the integration of the project into other urban and regional development activities is very fruitful. QUARREE100 is now not only recognised nationally and internationally, it is also an integral part of the integrated energy region, in the context of which the region is now receiving a wide range of enquiries about settlements.

However, the sometimes very long periods of time associated with the concepts, the planning processes and the subsequent implementation must be viewed critically. These time spans are not comprehensible for many citizens and therefore always require an attentive and open participation process. In this context, the balance between early transparent participation and the possible duration and sustainability of participation processes must always be evaluated.

The Entwicklungsagentur Region Heide (Heide Regional Development Agency) is of particular importance in this respect, as it acts both as a regional economic development agency and for the implementation of the urban-rural concept and as the coordinator of ENTREE100, and can enable such negotiation processes to become more permanent.

Overall, the concepts for Rüsdorfer Kamp and also the individual results from QUARREE100 should not be seen as an isolated island solution, but as a model and template for the development of other quarters and regions.

Network partners QUARREE100

QUARREE100 is embedded in the Solar Building/Energy Efficient City funding initiative as one of six funded projects in Germany. Twenty partners from research and industry form the QUARREE100 team, led by the Entwicklungsagentur Region Heide, the Advanced Energy Institute of the University of Bremen and the Steinbeis-Innovationszentrum Energie+ from Braunschweig.

Table 22.1: Network partners QUARREE100.

No.	abbreviation (short)	name	Street	ZIP & City
1	EARH	Entwicklungsagentur Region Heide AÖR	Hamburger Hof 3	25746 Heide
2	AES	Universität Bremen – Institute for Advanced Energy Systems	Enrique-Schmidt-Str. 7	28359 Bremen
	ARTEC	Universität Bremen – artec Forschungszentrum Nachhaltigkeit	Enrique-Schmidt-Str. 7	28359 Bremen
	UFT	Universität Bremen – Zentrum für Umweltforschung und nachhaltige Technologien	Leobener Strasse 6	28359 Bremen
3	SIZ	Steinbeis Innovationsgesellschaft energie+	Hamburger Str. 277	38114 Braunschweig
4	IFAM	Fraunhofer-Gesellschaft e.V. – Institut für Fertigungstechnik und Angewandte Materialforschung (IFAM)	Wiener Str. 12	28359 Bremen
5	FENES	Forschungsstelle Energiespeicher und Energienetze (FENES) an der Ostbayerischen Technischen Hochschule Regensburg (OTH Regensburg)	Seybothstraße 2	93053 Regensburg
6	JUB	Jacobs University Bremen	Campus Ring 1	28759 Bremen
7	FHWGG	Fachhochschule Westküste Umweltgerechte Gebäudesystemtechnik	Fritz-Thiedemann-Ring 20	25746 Heide
	FHWRS	Fachhochschule Westküste Steuerung / Prozessleittechnik / Netzintegration		
	FHWCB	Fachhochschule Westküste Green Energy / Energierecht und Recht der erneuerbaren Energien / Europäisches und internationales Wirtschaftsrecht		
8	DUE	Universität Duisburg-Essen, Abteilung für Finanzmarktökonometrie	Universitätsstraße 12	45117 Essen
9	ZSW	Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden–Württemberg (ZSW)	Meitnerstraße 1	70563 Stuttgart
10	IKEM	Institut für Klimaschutz, Energie und Mobilität – Recht, Ökonomie und Politik e.V.	Magazinstr. 15–16	10179 Berlin
11	SWHEI	Stadtwerke Heide GmbH	Hinrich-Schmidt–Str. 16	25746 Heide

Table 22.1 (continued)

No.	abbreviation (short)	name	Street	ZIP & City
12	ELO	ELOGEN GmbH	Eupener Straße 165	50933 Köln
13	IPP	IPP ESN Power Engineering GmbH	Rendsburger Landstraße 196–198	24113 Kiel
14	TACH	Tachycon GmbH	Hofholzallee 63	24109 Kiel
15	VATER	Vater Holding GmbH	Wasserwerksweg 18	24222 Schwentinental
16	EMMA	Emma Technologies GmbH	Felmer Straße 4b	24251 Osdorf
17	EEG	Energie- Einkaufs- und Service GmbH	Hamburger Str. 28	24558 Henstedt-Ulzburg
18	ENTEL	Entelios AG	Werinherstrasse 81	81541 München
19	HEI	Stadt Heide	Postelweg 1	25746 Heide
20	CON	Consolinno Energy GmbH	An der Donau 5	93080 Pentling

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Ilka Hoffmann

23 Renewable Energy Communities – A New Model for Neighbourhoods?

Summary: The implementation of innovative district energy supply concepts is difficult in Germany because the legal framework is not tailored to decentralised and interacting participants. A major obstacle are the charges and levies that currently account for around 65 percent of the total electricity price for private households and small businesses. These price components impair the economic viability of district supply projects. Another obstacle is the extensive catalogue of obligations for energy supply companies, which also applies to small producers in the district. With the Clean energy for all Europeans package of 2019, the European legislator wants to raise the potential of decentralised participants for decarbonisation and the transformation of the energy system. To this end, new decentralised participants, such as energy communities (associations of "small" local participants), were introduced and the member states were obliged to determine their contribution to the system costs (levies, network charges, taxes, etc.) based on a transparent cost-benefit analysis of distributed energy sources. In this regard, Member States can reduce the system costs for energy communities – also for those implementing district supply concepts – according to their benefits and improve the economic viability of district energy supply projects. In contrast to Austria, Germany has not yet implemented the legal figure of the energy community, but a regulation is planned in the revision of the Renewable Energy Sources Act (EEG 2023). While the Austrian regulations are based on the wording of the directive, German law will follow a different path. Although this will result in changes for district supply projects, no decisive improvement can be seen so far.

23.1 Introduction

District supply concepts are becoming increasingly important considering the ambitious climate protection goals and the simultaneously hesitant decarbonisation of the building sector.[1] According to the vision of the European legislator, the transformation of the energy system necessary to achieve the targets should succeed in a decentralised man-

1 Due to their importance for the transformation of the energy system, energy supply concepts for districts are being supported by the Federal Ministry of Economics and Technology and the Federal Ministry of Research with a total of 100 million euros, e.g. through the funding programme "Solar Building/Energy Efficient City". The QUARREE100 project is one of the six lighthouse projects.

Ilka Hoffmann, Fachhochschule Westküste, Institut für die Transformation des, Germany

https://doi.org/10.1515/9783110777567-023

ner and actively involve end-consumers. In this respect, the role of decentralised participants was strengthened by the Clean Energy Package and new participants such as energy communities (associations of “small” participants who implement energy projects) were introduced.

Since innovative district supply concepts both provide the technological prerequisites for a transformation of the energy system and contribute to an increase in the acceptance of renewable energies and efficiency measures by involving the residents of the district, the question is examined here as to what possibilities the European guidelines offer for innovative district supply projects.

23.2 District Management

The terms district, district supply and district supply concepts are generally used, but they are not conclusively defined.[2]

23.2.1 District

The term district is used in various disciplines, such as architecture, urban geography, urban sociology and the planning sciences, but is not conclusively defined in formal terms.[3] In the legal context, the term “district” is used, for example, in the Buildings Energy Act (Gebäudeenergiegesetz, GEG)[4] and the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG) 2021,[5] and the regulations and the explanatory memorandum to the EEG 2021[6] outline the idea of a district, at least for the scope of application of the EEG. However, a certain scope for assessment and interpretation remains.[7] As a result, districts are several buildings that are spatially connected, give the impression of a uniform ensemble and cover a radius of no more than 4.5 km.[8]

2 (dena, 2022, p. 61).

3 (Vollprecht/Ahlers/Albrecht 2018).

4 § 107 (1) Act on the Saving of Energy and the Use of Renewable Energies for Heating and Cooling in Buildings (Building Energy Act, GEG) of 8 August 2020 (Federal Law Gazette I p. 1728).

5 § 21 (3) (1) German Renewable Energy Sources Act as published on 16 July 2021 (Federal Law Gazette I p. 3026).

6 BT-Drs. 19/25326, p. 13.

7 Even if the term “district” can be concretised with the help of the interpretation of the law, this is associated with a certain degree of legal uncertainty, especially for grid operators who are responsible for distributing the tenant electricity surcharges.

8 (Buchmüller 2018).

23.2.2 District Supply Concepts

From a technical perspective, district supply concepts are energy supply solutions for districts.

While historically they mainly comprised the classic decentralised heat supply, district supply concepts are now increasingly characterised by versatility. They integrate renewable energies directly on site into the electricity and heat supply, combine different energy technologies with each other and can combine generation and consumption on site (load control) to provide system and flexibility services.[9]

Regular components of renewable district concepts are geothermal and solar thermal systems, heat pumps and heating grids, photovoltaic, wind energy and biomass systems as well as electricity and heat or cold storage, charging columns, intelligent metering systems, smart grids and power-to-x applications.[10]

Such supply solutions depend on the individual circumstances of the respective district. In many cases, they are unique and can differ considerably in terms of structure.[11] For example, the settlement and usage structure, the age and construction of the buildings, and the largely heterogeneous stakeholder structures of the respective district must be considered. District supply concepts usually integrate private households and smaller, sometimes also medium-sized commercial units and businesses, more rarely also industrial enterprises, both in new and existing buildings.[12]

23.3 Legal Framework for Electricity

A key component of innovative district supply concepts is the generation, storage and supply of renewable electricity within the district. With the increase in renewable generation, electricity in district supply concepts is not only used for direct consumption, but increasingly also for (intermediate) storage or conversion into other forms of energy (sector coupling), e.g. for conversion into heat and the operation of electric vehicles. Due to this “electrification of the energy system”,[13] the electricity-related legal framework has a significant influence on the economic viability of district supply projects.

9 (VKU, 2018, pp. 13,50,51).
10 (VKU, 2018, pp. 50,51).
11 (dena, 2022, p. 6).
12 (dena, 2022, p. 8 et seq.)
13 (dena, 2022, p. 11 et seq.)

23.3.1 Electricity Price Components (SIP)

A high proportion of the electricity price is made up of levies and charges. These so-called state-induced and regulated electricity price components currently account for about 65 percent of the total electricity price.

If the residents of a district are supplied with electricity which was generated in the district, this district supply is usually burdened with all electricity price components, which are added to the actual electricity price and collected via the supplier. It is irrelevant what the electricity is used for because everyone who buys electricity for their own consumption is considered to be an end-consumer and is subject to a basic payment obligation.[14] Except for privileges in electricity tax,[15] there are no exemptions for electricity that is demonstrably generated from renewable energies and sold to end-consumers in the district.

The electricity price components consist of grid charges,[16] ancillary grid charges such as concession levy,[17] Combined Heat and Power levy,[18] Electricity Network Fee Regulation Ordinance (StromNEV) levy,[19] offshore grid levy[20] and Interruptible Loads Agreements (AbLaV) levy,[21] as well as EEG-levy[22] and electricity tax,[23] irrespective of the grid charge system.

– Up to 25 percent of the average electricity price is caused by the grid charge.[24] It varies between approx. 5 and 10 ct/kWh due to the individual requirements of the

14 § 3 no. 25 German Industry Energy Act (Energiewirtschaftsgesetz – EnWG) as published on 10 August 2021 (Federal Law Gazette I p. 3436).

15 § 9 (1) (3) (b) German Energy and Electricity Tax Law (Stromsteuergesetz – StromStG) as published on 30 March 2021 (Federal Law Gazette I p. 607). In addition, a spatial connection is required, i.e. the tapping point must be located within a radius of no more than 4.5 km around the respective power generation unit.

16 § 17 German Regulation on Electricity Charges (Stromnetzentgeltverordnung – StromNEV) as published on 27 July 2021 (Federal Law Gazette I p. 3229).

17 § 48 German Industry Energy Act as published on 10 August 2021 (Federal Law Gazette I p. 3436).

18 §§ 26 ff. German Act on Combined Heat and Power Generation as published on 10 August 2021 (Federal Law Gazette I p. 3436).

19 § 19 (2) (2) German Regulation on Electricity Charges (Stromnetzentgeltverordnung – StromNEV) as published on 27 July 2021 (Federal Law Gazette I p. 3229).

20 § 17f German Industry Energy Act as published on 10 August 2021 (Federal Law Gazette I p. 3436) (EnWG).

21 § 18 (1) Verordnung zu abschaltbaren Lasten – AbLaV) as published on16 July 2021 (Federal Law Gazette I p. 3026).

22 §§ 60 ff. EEG 2021.

23 German Energy and Electricity Tax Law (Stromsteuergesetz – StromStG) as published on 30 March 2021 (Federal Law Gazette I p. 607).

24 (bmwk 2022).

respective grid operation and the different cost structures of the distribution grid operators.[25]

– The EEG levy, which was previously responsible for more than 20 percent of the electricity price at around 6 ct/kWh, was reduced to 3.723 ct/kWh from January 2022 and is expected to be reduced to zero.[26]
– The other levies amount to between 8 and 9 percent and under 3 ct/kWh.
– The electricity tax amounts to 2.05 ct/kWh[27] and accounts for under 6 percent of the electricity price.

23.3.2 Provider Obligations

Producers who supply electricity to end-consumers within a district are confronted with numerous obligations in their role as energy supply company (German abbreviation: EVU).[28] Since they are predominantly dealing with so-called household customers in the district, who are considered end-consumers, they must additionally observe consumer protection and transparency regulations. There are no exemptions for small companies or jointly operated district supply projects.

The fulfilment of these obligations is not only time-consuming and cost-intensive, but also entails economic risks.[29] Their duties include, for example, the obligation to bill and collect electricity price components as part of the electricity price. Depending on the contract constellation, the energy supply company becomes the debtor for the electricity tax,[30] which is usually passed on to the end-consumer.[31] This also applies to the grid-charge in so-called “all-inclusive contracts”. In addition, they must levy the EEG levy based on the kilowatt hour of electricity supplied to end-consumers and pass it on to the responsible transmission system operator.[32] Since the exact quantities

25 (Agora Energiewende/Hammerstein/Jahn et al., 2018, p. 4).
26 BT-Drs. 20/1025, p. 7, https://dserver.bundestag.de/btd/20/010/2001025.pdf.
27 § 3 German Energy and Electricity Tax Law (Stromsteuergesetz – StromStG) as published on 30 March 2021 (Federal Law Gazette I p. 607) (StromStG).
28 For sellers or suppliers of electricity, different terms are used depending on the law or ordinance, e.g. electricity supplier and supplier, and the definitions differ in detail, but in essence they are the same, so that this paper does not need to go into the differentiations in more detail and for simplicity the term EVU is used throughout.
29 E.g. EVU and the balancing group manager are jointly and severally liable for the payment of the EEG levy, § 60 (1) (4) EEG 2021. If they do not fulfil their obligation to pay on time, interest of five per cent will be due., § 60 (3) (1) EEG 2021.
30 § 5 (2)(1) German Energy and Electricity Tax Law (Stromsteuergesetz – StromStG) as published on 30 March 2021 (Federal Law Gazette I p. 607).
31 Electricity producers in the district who supply electricity to others must apply for a permit before they start supplying electricity and subsequently pay the electricity tax.
32 § 60 (1) EEG 2017.

supplied are unknown in advance, energy supply companies initially pay the transmission system operators a monthly instalment.[33]

In addition, energy suppliers must fulfil special information obligations towards household customers,[34] which are intended to serve as a basis for consumers to compare products and simultaneously serve competition and environmental protection,[35] while considering the basic requirements of comprehensibility and transparency.[36] In the event of customer complaints, they are obliged to participate in arbitration proceedings before the energy arbitration board and to bear the costs of the proceedings.[37] Although the law does not provide for any special sanction mechanisms for violations of information and transparency obligations, they may lead to supervisory measures by the regulatory authority[38] or claims for injunctive relief by competitors.[39]

23.3.3 Economic Efficiency

In the context of district supply concepts, all electricity price components are usually incurred for the local end-consumers, who are predominantly household customers, as each household or business is considered individually. Due to the separate consideration and the relatively small amounts of electricity in each case, no “volume discounts” can be considered. There are also no exemption or reduction options for district constellations.[40]

As there are no economic privileges associated with the local purchase of electricity, there is no economic incentive for residents to purchase their electricity from the district, nor to co-finance generation plants or to adapt their electricity consumption to the patterns of local generation plants.[41] Economic incentives could be provided, for example, by allowing residents to share in the added value created by consuming

33 (Lietz, 2021, margin no. 29).

34 This covers all end-consumers within the meaning of § 3 (25) EnWG who purchase energy primarily for their own household consumption or for their own consumption for professional, agricultural or commercial purposes not exceeding an annual consumption of 10,000 kilowatt hours.

35 (Heinlein/Weitenberg, 2021, margin no. 3ff.)

36 BR-Drs. 343/11, 214.

37 § 111 (b) German Industry Energy Act published on 10 August 2021 (Federal Law Gazette I p. 3436) (EnWG).

38 Aufsichtsmaßnahmen in the meaning of § 65 German Industry Energy Act published on 10 August 2021 (Federal Law Gazette I p. 3436) (EnWG).

39 Further details are regulated in „Gesetz gegen den unlauteren Wettbewerb (UWG).“.

40 One exception – but not specific to a district – is the electricity tax exemption, which applies if electricity is drawn from a renewable energy system with a maximum capacity of two megawatt within a radius of 4.5 km.

41 (dena, 2022, p. 66 et seq.)

locally fed-in electricity on site and preventing it from having to be redistributed at a loss and taking up capacity in the upstream grid.[42]

At the same time, there is also no economic incentive for operators of renewable electricity generation plants in a district to supply the residents in the district with renewable electricity, since on the one hand they are considered as a utility company when supplying final consumers and are fully exposed to the numerous associated obligations and economic risks that have to be priced in when calculating the profitability. On the other hand, they have no competitive advantages over other energy suppliers that they could pass on to the residents.[43]

23.4 Energy Communities in the Clean Energy Package

With the European "Clean energy for all Europeans package" (Clean Energy Package), the European legislator adopted a comprehensive package of measures in 2019 and significantly modified the legal framework that had been in force until then by means of a total of eight legal acts. In addition to anchoring the climate and energy policy goals until 2030, the package of measures contains extensive regulations to achieve these climate goals, on consumer participation and on restructuring the European electricity market.[44] Incentives for flexibility and innovation,[45] as well as requirements for new decentralised actors,[46] are contained in the Renewable Energy Directive (REDII)[47] and the Electricity Directive (IEMD).[48]

23.4.1 European Directives

In contrast to regulations, European directives are not directly applicable, but must be transposed into national law by the Member States. Therefore, they usually only contain binding targets and minimum standards, leaving the choice of form and means to achieve the targets to the national legislators.[49] In the absence of detailed specifications,

42 (Hoffmann/Brandstätt, 2021, pp. 8–9).
43 (Hoffmann/Brandstätt, 2021, pp. 8–9).
44 IEMD, Recital 3.
45 IEMD, Recital 9.
46 IEMD, Recital 4; REDII, Recital 63 and 65.
47 Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion ofnthe use of energy from renewable sources, ABl. L 328 v. 21.12.2018, 82–209.
48 Directive 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, ABl. L 158 v. 14.6.2019, 125–199.
49 (Nettesheim, 2021, margin no. 112 et seq.)

the individual regulations, especially the indeterminate secondary legislation provisions that are subject to interpretation, regularly require interpretation.[50]

23.4.2 REDII and IEMD

Being part of the Clean Energy Package, the two directives are closely linked, but they have different focuses. While the IEMD, which is open to all technologies, primarily regulates the restructuring of the European internal electricity market and the new rights for electricity customers, the REDII prescribes a common framework for the promotion of renewable energies.[51] According to the IEMD, the "new" European electricity market is to be designed in such a way that increasing amounts of renewable energy can be integrated and thus the renewable energy targets can be achieved by 2030.[52] The transformation of the electricity market should focus on system services, flexibility and decentralised actors such as customers, self-consumers and energy communities.[53] Accordingly, the position of self-consumers and Energy Communities is to be strengthened to achieve the binding overall target of the European Union for 2030.[54]

23.4.3 Legal Figure Energy Community

Two types of energy communities are enshrined in the Clean Energy Packages. On the one hand, the Citizen Energy Community (CEC)) in the IEMD and, on the other hand, the Renewable Energy Community (REC) in the REDII. Since the scope of the Citizen Energy Community (CEC) is limited to the electricity market and innovative district supply concepts also include heat supply, the CEC is likely to be negligible as a legal figure for the implementation of innovative district supply concepts.[55] Therefore, the focus is on the legal figure of the REC.

RECs can operate across sectors, but only in the field of renewable energies. Their scope of activity includes the production, consumption, storage and sale[56] as well as the joint use of renewable energies produced within the REC (also known as energy

50 (Kaufmann, 2021, pp. 299ff).
51 REDII Article 1 (1).
52 (Hoffmann 2021).
53 IEMD Recital 4, (Wimmer 2020).
54 (Schulz/Losch 2017).
55 (Hoffmann 2021).
56 REDII Article 22 (2) (a).

sharing)[57] Accordingly, this also includes the production and consumption of heat, as long as the heat comes from renewable energies.[58]

The central requirement for RECs is that their primary purpose is not to generate financial profits, but to achieve "regional added value", such as local environmental, economic or social community benefits for its shareholders or members.[59] However, the phrases "primarily" and "to a lesser extent" make it clear that this is not an absolute "ban on profit", but that economic benefits for the benefit of members are also permissible,[60] as long as the main focus is on the maximisation of a community benefit.[61]

The actors that can participate in a REC are listed exhaustively in the REDII.[62] These include natural persons, local authorities including municipalities, and small and medium-sized enterprises (SMEs). At the same time, effective control must come from shareholders located close to the projects[63] and the REC must be "independent"[64] so that traditional market actors cannot exert a proportionate influence on decisions within the REC, e.g. through investments.[65] Accordingly, only "small" players can participate.[66]

Furthermore, participation in a REC must be voluntary and in principle open to all intended participants[67] and low-income consumers or households in need,[68] to contribute to combating energy poverty.[69]

Finally, the generation facilities must be owned by the REC.[70]

23.4.4 District Energy Supply Communities

Whether actors who wish to jointly implement a district energy supply concept can join as a REC depends primarily on the respective energy and business concept. As explained above,[71] activities outside the electricity sector can also be considered for

57 REDII Article 22 (2) (b).
58 (ReScoop.EU/ClientEarth, 2020, p. 44).
59 REDII Article 2 (16) (c).
60 (ReScoop.EU/ClientEarth, 2020, p. 17 et seq.)
61 (Caramizaru/Uihlein, 2020, p. 33).
62 REDII Article 2 16) (b).
63 (Hoffmann 2021).
64 REDII Article 2 (16).
65 REDII Recital 71.
66 REDII Article 2 (16) (b).
67 REDII Article 2 (16) (a).
68 REDII Article 22 (4) (f).
69 REDII Recital 67.
70 (Hoffmann 2021).
71 Cf. chapter 23.4.3.

RECs. For example, renewable energy associations can also operate in the field of renewable heat, as long as it is exclusively renewable energy. Furthermore, the activities of RECs are not limited to the joint production of energy, but also include the consumption, storage and sale[72] as well as the joint use of renewable energies produced within the REC. In this respect, it is conceivable that a REC e.g. jointly operates photovoltaic systems and uses the generated green electricity for the operation of electric vehicles or heat pumps, and the latter feed into a heating network that is fed exclusively by renewably generated heat and supplies the district. However, it is likely to be problematic if fossil fallback options are part of the district supply concept. A Combined Heat and Power unit powered by natural gas – even in emergencies such as dark lulls – could be an exclusion criterion, as RECs are limited to 100 percent renewables. Particularly in the case of complex concepts that are composed of numerous different components for resilience reasons or to provide system services, the question arises as to whether and, if so, at what price such an exclusivity can be mapped.[73] Fulfilment of the criterion of 100 percent renewability throughout is likely to be associated with high costs, especially for large districts with a high energy demand and many different components. It should therefore be examined whether exceptions or special regulations are needed for these constellations, which are particularly valuable for the transformation of the energy system due to their flexibility.

23.5 Requirements for Privileged Treatment

The directives lack any concrete or conclusive specifications on the privileges of energy communities. However, one of the stated aims of the directives is to enable decentralised actors to actively participate in the market.[74]

23.5.1 Promotion of RECs

In this respect, the REDII requires Member States to establish a regulatory framework that supports and promotes the development of RECs.[75] They must ensure that RECs can carry out certain activities and are granted non-discriminatory market access and a level playing field. However, the wording is general, such as “Member States shall provide an enabling framework to promote and facilitate the development of renewable

72 REDII Article 22 (2) (a).
73 (dena, 2022, p. 64 et seq.)
74 (Papke 2019).
75 REDII Article 22 (4) (1).

energy communities (. . .)"[76] and accordingly does not contain any specific privileging elements.

23.5.2 Participation in System Costs – Cost-Benefit Analysis

The provisions on the participation of RECs in system costs are somewhat more concrete. It is true that, in principle, they participate in the system costs and are subject to the general principles of the grid charging system.[77] At the same time, however, it is anchored that the participation of RECs in the system costs should be based on a transparent cost-benefit analysis of the decentralised energy sources or resources.[78] The determination of system costs based on a cost-benefit analysis, as opposed to concrete specifications, as in the case of self-supply, is the result of controversial trialogue negotiations.[79]

Cost-benefit analyses primarily serve as an economic instrument for weighing up costs and benefits and are regularly used in both German and EU law. The REDII, for example, provides for cost-benefit analyses in connection with self-supply[80] and the common rules for the internal market for electricity and amending (EBM-RL)[81] for smart metering systems. As a rule, there are no concrete specifications for the design of cost-benefit analyses, but it is left to the Member States – as in this case – to decide which effects are to be included in the calculation and how they are to be evaluated in relation to each other. It also remains open whether the same criteria should apply to all electricity price components or whether, for example, different parameters should be used for network charges than for concession fees. If electricity price components -related differentiations of the criteria were to be made, it would have to be decided how non-energy aspects could be assigned and evaluated.[82]

However, in the recitals the European legislator lists numerous positive effects associated with decentralised energy production in general and Renewable Energy Communities.[83] In doing so, it not only underlines the high importance of Renewable Energy Communities for the transformation of the energy system, but also specifies

76 REDII Article 22 (4) (1).

77 REDII Recital 71.

78 REDII Article 22 (4) (1d).

79 (Kahles/Pause 2019).

80 Article 21 of the REDII requires a cost-benefit analysis of self-supply installations from 1 December 2026 if the total share of self-supply installations exceeds 8 percent of the total installed electricity generation capacity in a Member State.

81 Annex II of the IEMD contains specifications regarding a cost-benefit analysis for smart metering systems.

82 (Hoffmann/Brandstätt, 2021, p. 11).

83 REDII Recital 65 contains the formulation „Mit dem Übergang zur dezentralisierten Energieproduktion sind viele Vorteile verbunden, (. . .)", which are listed below.

which aspects are to be included in the assessment of the benefits. These include improved local energy security,[84] the fight against energy poverty,[85] the promotion of energy efficiency, and the positive effects on the development and cohesion of the community through the creation of place-based livelihoods and jobs.[86] Finally, Renewable Energy Communities make a significant contribution to the acceptance of renewable energy, access to additional local private capital and the associated participation of citizens in the energy transition highlighted,[87] as well as benefits to the energy system through sustainable generation.[88]

23.6 Implementation in Germany

So far, neither of the two energy community forms has been transposed into German law.[89] Nor has any cost-benefit analysis of decentralised energy sources been legally provided for or published, although the REDII must be implemented by 30 June 2021.[90]

Now the requirements of the REDII on RECs shall be implemented during the upcoming amendment of the Renewable Energy Sources Act). In essence, the requirements of § 3 no. 15 EEG 2023[91] are to be significantly tightened and a citizens energy company will in future consist of at least 50 natural persons as voting members or voting shareholders, whereby at least 75% of the total voting rights must be held by natural persons. In accordance with the provisions of the REDII, in addition to natural persons, only micro-enterprises, small and medium-sized enterprises and local authorities, including municipalities, may participate in citizens' energy companies. In total, none of the members or shareholders may hold more than 10% of the voting rights in the company.[92]

As a privilege, citizens' energy companies that implement wind energy projects of up to 18 megawatt or solar projects of up to 6 megawatts are to be exempt from the obligation to participate in tenders.[93] With the anchoring of maximum limits, the law is

84 REDII Recital 65 (2 and 3).
85 REDII Recital 67 (2).
86 REDII Recital 65 (2 and 3).
87 REDII Recital 70.
88 REDII Recital 70.
89 The spring amendment of the German Renewable Energy Sources Act EEG 2021 came into force in July 2021 and does not contain any regulations on RECs.
90 REDII Article 1 (1).
91 Draft EEG 2023, p. 21, https://www.bmwi.de/Redaktion/DE/Downloads/Energie/04_EEG_2023.pdf?__blob=publicationFile&v=8 (Accessed:17 April 2022).
92 Draft EEG 2023, p. 21, https://www.bmwi.de/Redaktion/DE/Downloads/Energie/04_EEG_2023.pdf?__blob=publicationFile&v=8 (Accessed:17 April 2022).
93 Draft § 22b EEG 2023, https://www.bmwi.de/Redaktion/DE/Downloads/Energie/04_EEG_2023.pdf?__blob=publicationFile&v=8 (Accessed:17 April 2022).

adapted to the de minimis requirements of the new Guidelines on State aid for climate, environmental protection and energy of the European Commission of 27 January 2022.[94]

As a result, according to the current draft law, the only privilege for citizen energy companies is that they do not have to participate in the tendering procedure and are protected from the existing award risk and the associated threat to their existence if they are not awarded the contract.[95] It remains to be seen what the consequences will be of the Federal's Office for Economic Affairs and Export Control planned support programme, which is intended to support citizens' energy companies in the planning and approval phase for onshore wind turbines.[96] Solar projects, however, cannot benefit from the support. An adjustment of the system costs by means of a cost-benefit analysis or the possibility of energy sharing has not yet been provided for.

23.7 Implementation in Austria

In Austria, RECs were introduced into the Renewable Energy Expansion Act (EAG) in July 2021.[97] The general provisions on RECs can be found in section 79 EAG. As a result, the wording of the REDII was almost completely adopted. Accordingly, it is stipulated that RECs may produce energy from renewable sources, consume, store or sell their own generated energy, and that only natural persons, municipalities, legal entities of public authorities in relation to local services and other legal persons under public law or SME may participate in RECs. To enable municipal companies to participate in RECs, the Austrian legislator has provided for exceptions from the Commission recommendation on SME, so that "small" municipal companies can participate under certain conditions.[98] The draft of the EEG 2023 does not contain a corresponding regulation for citizens' energy associations.

Austrian law provides several privileges for RECs. For example, internally generated but not consumed electricity can be subsidised up to a maximum of 50 percent,[99]

94 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022XC0218(03)&from=EN (Accessed: 17 April 2022).
95 Draft EEG 2023, p. 162, https://www.bmwi.de/Redaktion/DE/Downloads/Energie/04_EEG_2023.pdf?__blob=publicationFile&v=8 (Accessed:17 April 2022).
96 Draft EEG 2023, p. 162, https://www.bmwi.de/Redaktion/DE/Downloads/Energie/04_EEG_2023.pdf?__blob=publicationFile&v=8 (Accessed: 17 April 2022).
97 https://www.parlament.gv.at/PAKT/VHG/XXVII/BNR/BNR_00348/fname_989096.pdf (Link of the legal text) (see https://www.parlament.gv.at/PAKT/VHG/XXVII/BNR/BNR_00348/index.shtml) (Accessed: 17 April 2022).
98 (Krönke/Tschachler 2021).
99 § 80 (2) (1) Austrian Renewable Energy Sources Act (EAG).

the renewable subsidy for internally consumed electricity does not apply,[100] internally generated and consumed photovoltaic electricity is exempt from the electricity levy and grid fees are reduced.

23.8 Conclusion

The REDII obliges Member States to enable decentralised actors to actively participate in the market. For the implementation, it offers national legislators a wide scope to promote associations acting as RECs according to their benefits. While Austria has anchored comprehensive support regulations for RECs on this basis, a comparable implementation in Germany is missing so far, although "district supply communities" could make a significant contribution to the transformation of the energy system and the achievement of climate goals, especially in the heating and building sector.[101] To exploit this potential, it is imperative that German law also provides sufficient incentives for the implementation of innovative district supply concepts and that a regulatory framework for joint energy projects, such as RECs, is created.

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100 This is comparable to the EEG levy.

101 (dena, 2022, p. 64 et seq.)

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Judith Schäfer, Ilka Hoffmann, Christian Buchmüller

24 Integration of Heat Consumers into Green Heating Networks – Municipal Control Instruments

Summary: Municipalities have a range of urban planning instruments at their disposal to integrate as many heat consumers as possible into a green 'local heating network'. This paper first out-lines the various instruments available within the framework of a development plan and highlights the limits arising from the constitutional protection of existing buildings (Article 14 of the Basic Law). It then describes how an urban development contract can increase the density of connections to a local heating network, though with the caveat that the municipality is always dependent on the willing participation of potential contract partners with this approach. Finally, the paper considers the implications of an obligation to connect to and use a municipal heating network, examining the requirements that must be met as well as the advantages and disadvantages of this option.

24.1 Background

QUARREE100[1] is a research project investigating the efficient energy supply of urban districts. The project aims to upgrade the energy system and refine plans for urban development in an existing district of roughly 500 inhabitants, which occupies an area of approximately 20 hectares in Heide, Schleswig-Holstein. An energy concept that was developed for this purpose focuses on the construction and operation of a 'local heating network' to supply households in the district (existing buildings and new buildings). Most of the heat is to be generated by large heat pump systems, and the electricity required to operate the system is to be produced, to the greatest extent possible, in the district. To this end, the plan calls for the installation of photovoltaic systems on as many roofs as possible in the district; these systems will supply the produced electricity directly to the heat generation systems. The transport is to take place

1 The full title of the project is 'QUARREE100 – Resilient, integrated and system-serving energy supply systems in existing urban neighbourhoods with full integration of renewable energies'. For more information, visit https://www.ikem.de/en/quarree100/ (Accessed 24 May 2022). Additional details are available on the project website: https://quarree100.de/ (Accessed: 24 May 2022).

Judith Schäfer, IKEM, Germany
Ilka Hoffmann, Fachhochschule Westküste, Institut für die Transformation des Energiesystems, Germany
Christian Buchmüller, Fachhochschule Westküste, Institut für die Transformation des Energiesystems, Germany

https://doi.org/10.1515/9783110777567-024

via an electrical operating network that is being developed specifically to supply power to the technical systems within the heating network.

The number of households that are connected to and cover their heating needs from the 'local heating network' is significant not only for the purposes of cost-effective network operation, but also for the realisation of the project's full climate change mitigation potential.[2] It was therefore necessary to examine the municipal control instruments available in the community to integrate as many consumers as possible into a local green heating concept. This paper considers the potential of three such instruments: urban land-use planning (24.2), the urban development contract (24.3) and the introduction of provisions that make connection and usage compulsory under public law (24.4).

24.2 Urban Land-use-Planning

Because urban land-use planning specifies the spatial structure for heat generation, distribution and consumption as well as the relevant technical requirements, it can be used to unilaterally control heat planning. The German Building Code (Baugesetzbuch, BauGB)[3] entitles the municipality to make corresponding representations or designations for its municipal area, both in the land-use plan [*Flächennutzungsplan*] in accordance with § 5 BauGB and in the development plan [*Bebauungsplan*] in accordance with § 9 BauGB. The land-use plan does not have any direct legal effects, however;[4] it serves only to control land use in the municipality and, accordingly, contains coarse-meshed representations. The type of land use is therefore presented only in general terms (cf. § 5 (1) (1) BauGB). More detailed representations for the purpose of controlling heat usage would be beyond the scope of the land-use plan; differentiated control is thus reserved for the development plan, as a binding plan for urban land use. The following discussion will therefore focus on the development plan.

The building planning instruments available to municipalities have steering effects that vary in scope depending on whether the district's structures are existing buildings or new constructions. This difference is due to the freedom of ownership provided for under Article 14 of the Basic Law (GG), as well as to the resulting protection of existing buildings granted under building law. This protection enables the specific use allowed within the parameters of a permit or the eligibility for a permit to continue regardless of any disadvantageous changes later made to the law, provided that a structure has been legalised by the permit or has been lawful under the provi-

2 (Schäfer-Stradowsky/Doderer, 2018, margin no. 14).

3 Building Code (Baugesetzbuch) as published on 3 November 2017 (Federal Law Gazette I p. 3634).

4 (Jaeger, 2021, margin no. 12).

sions of material law for a minimum period of time.[5] The owner of a legally approved building or – if the building project did not require a building permit – of a physical structure that is temporarily lawful under material law is therefore not obligated to comply with subsequent changes to the law, such as alternative requirements in the development plan. This right of the owner is called the 'passive grandfathering' [*passiver Bestandsschutz*].[6] The protection of existing buildings under building law goes even further: 'active grandfathering' [*aktiver Bestandsschutz*] entitles the owner to carry out measures to maintain, repair or modernise to ensure functional use, even if such measures would no longer be permissible under the applicable building law.[7] These measures are permitted only if the physical structure of the building remains intact, however.[8] This protection only applies to existing buildings; when constructing a new building, owners are generally required to observe the municipal requirements for planning buildings.

24.2.1 Requirements in the General Development Plan – Prohibitions and Restrictions on Use

In the framework of a development plan, the municipality can impose (binding) regulations on the type and extent of building use, the areas of land that can be developed and the local traffic areas (cf. § 30 (1) BauGB). The possible content of the provisions of a development plan is conclusively regulated by § 9 BauGB.[9]

In order to secure the purchase of heat in the district by property owners, the municipality can, for example, designate areas in the development plan where certain air polluting substances may not be used, or may be used only to a limited extent, in order to protect against harmful effects on the environment, in accordance with § 9 (1) (23) (a) BauGB. 'Harmful environmental impacts' are immissions which, due to their nature, extent or duration, are likely to cause hazards, significant disadvantages or significant nuisance to the general public or to the district (§ 3 (1) of the Federal Immission Control Act, BImSchG). Article 3 (4) BImSchG defines 'air pollutants' as any change in the natural composition of the air, especially through smoke, soot, dust, gases, aerosols, fumes or odorous substances. The requirements specified in § 9 (1) (23) (a) BauGB are primarily applied in the form of prohibitions or restrictions on the use of certain heating fuels,

5 (Beckmann 2014); BVerwG, decision of 16 December 1988, ref.: 4 NB 1/88 (Mannheim), NVwZ 1989, 664 (665).
6 (Beckmann 2014); BVerwG, decision of 16 December 1988, ref.: 4 NB 1/88 (Mannheim), NVwZ 1989, 664 (665).
7 (Beckmann 2014); BVerwG, decision of 16 December 1988, ref.: 4 NB 1/88 (Mannheim), NVwZ 1989, 664 (665).
8 (Beckmann 2014).
9 (Spannowsky, 2021, preceding margin no. 1).

such as coal, oil or wood.[10] A general exclusion of masonry heaters or fireplaces is not possible.[11] Although its wording addresses both new and existing buildings, the requirement only directly affects new buildings and conversions, as well as significant extensions of existing buildings, since, as noted above, existing buildings are unaffected by later changes to the requirements in the development plan.

If a requirement is set pursuant to § 9 (1) (23) (a) BauGB, the municipality must ensure that the prohibition or restriction of use is possible with state-of-the-art technology and economically reasonable for the property owner.[12] This means, in particular, that the heat supply must be ensured by other means – for example, by local or district heating – in the area covered by the development plan. In this case, the energy suppliers have an obligation to contract, and are obligated to conclude the corresponding contracts with the property owners.[13] The property owners, however, are not obligated to connect to and use a specific heat supply; the purchase of heat is not compulsory.[14] Compulsory connection and usage can only be established by municipal ordinance (see Section 24.4 below).[15]

In addition, the municipality can only make requirements in the development plan for reasons related to urban development. Other reasons – such as objectives to increase energy-efficient consumption of certain heating fuels or pursue general environmental goals, such as a reduction in greenhouse gas emissions – are not sufficient.[16] In addition, § 9 (1) (23) (a) BauGB prohibits requirements that are intended to grant competitive advantages to certain energy supply companies through an expansion of their customer base.[17] Reasons related to urban development must include a reference to land law. This condition is satisfied if, for example, the aim of a ban or restriction on the use of individual heating fuels is to provide certain areas – such as hillside locations, health resorts or local recreation areas – with special protection from air pollution.[18] The municipality may also impose a requirement of this kind if it is interested in improving the air quality in its municipal territory.[19]

10 (Spannowsky, 2021, margin no. 93).
11 (Spannowsky, 2021, margin no. 94.4).
12 (Spannowsky, 2021, margin no. 95).
13 (Spannowsky, 2021, margin no. 95.1).
14 (Spannowsky, 2021, margin no. 95.1).
15 (Spannowsky, 2021, margin no. 95.1).
16 BVerwG, NVwZ 1989, 664.
17 (Söfker, 2021, margin no. 191).
18 (Spannowsky, 2021, margin no. 95).
19 BVerwG, NVwZ 1989, 664 (664).

24.2.2 Requirements in the General Development Plan – Measures for the Use of Renewable Heat

§ 9 (1) (23) (b) BauGB entitles the municipality to designate certain areas as requiring specific structural or technical measures for the generation, use or storage of electricity, heating or cooling from renewable energies or combined heat and power (CHP) in new constructions. Property owners may therefore be obligated to take certain measures.[20] In the context of heat usage, for example, this may involve the technical installation of a connection to a heating network.[21] The wording of § 9 (1) (23) (b) BauGB refers only to new buildings, however, and property owners are not obligated to use renewable energies or CHP. This provision also requires reasons related to urban development (see Section 24.2.1 above).

The option to establish requirements that is granted by § 9 (1) (23) (b) BauGB is distinct from the regulations of energy law, some of which impose an obligation to use renewable energies or CHP.[22] Of particular relevance here is the German Building Energy Act (Gebäudeenergiegesetz, GEG),[23] which prescribes for all new buildings that are heated or cooled using energy – with the exception of the buildings cited in § 2 (2) GEG – a proportional obligation to meet heating and cooling needs with renewable energies or through alternative measures (local and district heating supply, CHP). Depending on the input material, the usage obligation can range from 15–50% (see §§ 35 ff. GEG). If the intended share of renewable energies is already covered by the provisions of the GEG, a requirement in building planning law may be unnecessary. Because one of the tasks of urban land-use planning is to contribute to climate change mitigation and to the use of renewable energies (cf. § 1 (5) (2) BauGB), however, the GEG does not prohibit such a requirement.[24]

24.2.3 Other Instruments of Building Planning Law

The project-related development plan, which is prepared in accordance with § 12 BauGB, is a useful instrument for municipalities that seek to leave the concrete project planning to the developer, establish planning requirements that go beyond those specified in § 9 BauGB, and/or have the developer bear the costs. In contrast to the general development plan, the project-related development plan is intended to establish more of a cooperation between the municipality and the developer than a unilateral control of land use. A

20 (Söfker, 2021, margin no. 197a).
21 (Söfker, 2021, margin no. 197e).
22 (Söfker, 2021, margin no. 197a).
23 Act on the Saving of Energy and the Use of Renewable Energies for Heating and Cooling in Buildings (Building Energy Act, GEG) of 8 August 2020 (Federal Law Gazette I p. 1728).
24 (Söfker, 2021, margin no. 197a).

'project and development plan'[25] is initially prepared by the developer and later becomes part of the development plan (cf. § 12 (3) (1) BauGB). Because the municipality is not bound by the regulatory options prescribed in § 9 BauGB and the Federal Land Utilisation Ordinance (Baunutzungsverordnung, BauNVO)[26] (cf. § 12 (3) (2) BauGB), it has more options to design provisions. In addition, an implementation agreement obligates the developer to realise and bear the costs of the project and to implement it within a certain time period.[27]

Recourse to redevelopment law (§§ 136 ff. BauGB) as a limited special right[28] is also possible. §§ 136 ff. BauGB permits redevelopment measures to be implemented as uniform, coordinated, comprehensive measures in the relevant district.[29] This grants the municipality far-reaching powers to intervene in the rights of those affected by redevelopment,[30] which are intended to ensure that the measures are carried out quickly. In addition, § 164a BauGB permits access to urban development funds to finance the redevelopment measures. However, the municipality may only take urban redevelopment measures if there are existing deficits in urban planning and if the planned measures are intended to substantially improve or redesign the affected area (§ 136 (2) BauGB). § 136 (2) and (3) BauGB specify the conditions under which deficits in urban planning exist.

Construction measures, as defined in § 148 BauGB, are one of the central instruments for carrying out redevelopment.[31] In this respect, § 148 (2) (1) (5) BauGB provides for the construction or expansion of plants or facilities for the use of heat from renewable energies or CHP. This also includes the connection to a heating network. The municipality can thus integrate heat consumers into green heating networks through appropriate construction measures. However, a construction measure of this kind does not justify a usage obligation on the part of the owner.[32]

25 (Busse, 2021, margin no. 3).

26 Building Use Ordinance (Baunutzungsverordnung) as published on 21 November 2017 (Federal Law Gazette I p. 3786), last amended by Art. 2 of the Building Land Mobilisation Act (BaulandmobilisierungsG) of 14 June 2021 (Federal Law Gazette I p. 1802).

27 (Busse, 2021, margin no. 3).

28 (Schmitz, 2021, margin no. 1).

29 (Schmitz, 2021, margin no. 4 ff.)

30 (Schmitz, 2021, margin no. 12).

31 Cf. § 146 (1) BauGB.

32 (Mitschang/Reidt, 2022, margin no. 137), on a formulation in § 9 (1) (23) (b) BauGB that is similar to § 148 (2) (1) (5) BauGB.

24.3 Urban Development Contracts

Municipalities can increase the density of connections to a local district heating network by specifying requirements for the construction, connection and use of heat from the corresponding district heating network in an urban development contract.[33] In contrast to requirements under building planning law, urban development contracts can also apply to existing buildings.

This instrument – which usually involves cooperation with private parties ('public-private partnership')[34] – has numerous advantages. First, the municipality is not bound by the catalogue of provisions in § 9 (1) BauGB[35] and can establish rules that would not be permissible in a development plan,[36] while at the same time taking into account the specific features of individual cases.[37] Second, urban development contracts can play a significant role in speeding up the procedure, as they allow for an agreement on deadlines for the implementation of the building project.[38] And third, private parties can be obligated to bear the costs of certain climate change mitigation measures that could not have been financed from the municipal budget.[39]

Due to freedom of contract and disposition, urban development contracts are always based on voluntariness, i.e. the parties involved decide whether to enter into an urban development contract. This increases the acceptance and durability of the planned projects.[40] It also means, however, that the municipalities cannot force parties to enter into an urban development contract and that the decisive factor is the (generally economic) attractiveness of the project to potential contract partners. The negotiating power will therefore lie with the municipality if demand is high and the use and implementation of measures is economically attractive to private investors.[41]

33 § 11 (1) (2) (4) BauGB.

34 Although contracts between municipalities are also conceivable, in practice the focus is on cooperative forms of action between municipalities and persons under private law.

35 (Kahl/Schmidtchen, 2013, p. 179).

36 (Sparwasser/Mock 2008).

37 Federal Ministry of Transport, Building and Urban Affairs, *ImmoKlima*, p. 65, BT-Drs. 13/6392, p. 38; (Kahl 2000).

38 (Mainka, 2018, p. 58).

39 Because it lowers public spending, the urban development contract has become one of the most important planning instruments when budgets are tight. In some cases, municipalities only draw up or amend development plans after the beneficiaries of such plans have entered into a contract that secures a corresponding assumption of costs and regulates the full or partial assumption of subsequent burdens. For further discussion on this topic, (Reidt, 2022, margin no. 3), (Mainka, 2018, p. 59), On the economic advantages of urban development contracts and various strategies to mobilise building land for municipalities, see also Baulandmobilisierung und städtebauliche Verträge, DStGB documentation no. 9, Deutscher Städte- und Gemeindebund.

40 (Mainka, 2018, p. 59).

41 (Reidt, 2022, margin no. 4).

In practice, requirements for a climate-friendly heat supply are therefore often linked to a municipal land-purchase agreement.[42]

24.3.1 Energy-Related Subject Matters of Contracts

The central regulation applicable to urban development contracts is § 11 BauGB, which does not contain an exhaustive list of contract types and subjects.[43]

The subject matter of contracts related to the climate-friendly supply of heat is regulated in § 11 (1) (2) (4) BauGB. This section was expanded with the 2011 revision of the BauGB, known as the 'climate agreement'; it now expressly includes the construction and use of systems and facilities for the generation, distribution and use of heat from renewable energies or CHP. The amendment clarified that the installation and use of renewable energy systems can be the subject of agreements related to individual buildings and to community systems and heat grids; this is akin to a contractual obligation to connect and use.[44] Corresponding contractual designs are used in practice and have been recognised for some time.[45]

24.3.2 Reasonableness

The services agreed upon by the parties must be reasonable under the overall circumstances.[46] This requirement stems from the principle of proportionality and requires the economic value of the performance to be commensurate with the consideration.[47]

The overall circumstances of the individual case must be taken into account, i.e. there must be a comprehensive assessment of the resulting burdens, as well as the advantages for the private contractual partner,[48] including the profitability of the investments made by the developer and the increase in property value resulting from municipal planning. Factors that must be considered include the commitment period, the ability of the plant operator to operate the plant profitably,[49] and the potential for the additional costs incurred to be considerably higher than the energy costs that would otherwise be customary on the market.[50]

42 (Kahl/Schmidtchen, 2013, p. 187f.)

43 The use of the words 'in particular' in § 11 (1) (2) BauGB indicates that the list is not exhaustive.

44 (Hehn, 2015, p. 339).

45 (Kahl/Schmidtchen, 2013, p. 188f.)

46 § 11 (2) (1) BauGB reads: 'Contractually agreed obligations must be reasonable under the overall circumstances.'

47 (Hendricks, 2006, pp. 45ff.) (Reidt, 2022, margin no. 75).

48 (Reidt, 2022, margin no. 75).

49 (Mainka, 2018, p. 80).

50 (Mainka, 2018, p. 80).

24.3.3 Prohibition(s) of Coupling

In addition, a contract may not obligate the contracting party to do something to which the contracting party would have been entitled even without this obligation (prohibition of coupling).[51] This would be the case, for example, if there were already a claim to the granting of a building permit.

In addition, performance and consideration must have a direct material connection to each other.[52] This means that there must be a causal connection between the planned project and the costs to be assumed, which is especially an issue in follow-up cost agreements pursuant to § 11 (1) (2) (3) BauGB. For example, the project developer can only be required to assume costs arising from the specific construction project.

Finally, with regard to the content of urban development contracts, a municipality may not, by virtue of its discretion over the planning process, make its decisions dependent on the developer's consideration. § 1 (3) (2) BauGB also explicitly states that there is no entitlement to the preparation of urban land-use plans and urban development ordinances and that such an entitlement cannot be justified by a contract.

24.3.4 Reasonableness of General Terms and Conditions (GTC) and the Requirement of Written Form

If the urban development contract is a contract under civil law or if the contract at least contains elements of civil law (usually in the case of urban-planning references), the law pertaining to GTC [*AGB-Recht*] must be observed.

In addition, urban development contracts must be in writing. If a simultaneous real estate transaction is associated with the contract, notarial certification is also required.

24.3.5 Implementation Agreement (Project-Related Development Plan)

As noted in Section 24.2.3, for new-build projects on private land, the municipality can enter into an urban development contract in the form of an implementation agreement for the project-related development plan (§ 12 BauGB), which obligates the municipality to carry out the urban planning process for the project and for the development measures. In addition, the developer is obligated to complete the project, bear its costs, and

51 § 11 (2) BauGB reads: '(2) An agreement on a service to be rendered by a contracting party is impermissible if that party would be entitled to the consideration even without the agreement.'
52 (Hendricks, 2006, pp. 39ff.)

implement it within a certain period of time. As a result, an implementation agreement can specify all of the obligations related to climate change mitigation that are permissible in urban development contracts under the terms of § 11 BauGB. Accordingly, the implementation agreement may establish binding regulations for implementing the energy-related aspects of the project. If a project developer is interested in preparing the project and the development measures, the municipality can specify conditions for the construction and operation of a 'local heating network' in the implementation agreement for the project-related development plan.

It must be taken into account that the implementation agreement between the developer and the municipality must be concluded prior to the adoption of the ordinance by resolution, and thus prior to the resolution on the project-related development plan pursuant to § 10 (1) BauGB.

24.3.6 Urban Redevelopment

Urban development contracts can also be concluded in connection with the granting of a permit under redevelopment law if doing so eliminates grounds for refusal.[53] Accordingly, within the framework of a redevelopment area, the municipality can also contractually obligate an owner who applies for the approval of a construction project in a redevelopment area to connect to a climate-friendly district heating network source and to consume heat.

24.3.7 Land-Purchase Agreements

A concept award is a suitable procedure for the sale of land if the decision to sell is not based on the highest price bid and if the municipality seeks to influence the building project and make its decision dependent on factors such as the fulfilment of ecological and/or social criteria. State, federal and European legal requirements must be taken into account.

In municipal land sales, a municipality can also create an easement that obligates the purchaser of the land to meet heat demand with energy from a climate-friendly source (e.g. a local district heating network).

53 § 145 (4) (3) BauGB.

24.4 Compulsory Connection and Usage

Municipalities can also increase the density of connections to a local district heating network by making connection and usage compulsory under public law. This always requires the enactment of a municipal ordinance (district heating ordinance). Under the terms of a district heating ordinance, all properties located in the area that is subject to the ordinance must connect to the district heating network and use the district heating network to meet their heating needs in full.[54] In principle, this requirement applies to both new and existing buildings, though with restrictions for existing buildings due to the principle of proportionality. During the implementation process, it may be necessary to comply with special tendering obligations from cartel law or public procurement law.

Municipalities in Schleswig-Holstein can base the enactment of district heating ordinances on authorisation granted by either a state law[55] or a federal law.[56]

24.4.1 Enactment of a District Heating Ordinance Based on GO Schleswig-Holstein

In addition to the formal requirements that must be taken into account, the following material requirements must be met in order to enact a district heating ordinance based on § 17 (2) of the Municipal Code of Schleswig-Holstein (GO Schleswig-Holstein):[57]

– **District heating ordinances serve global climate change mitigation goals**
As a 'public institution' [*öffentliche Einrichtung*], the district heating supply must serve 'the protection of health and the protection of the natural foundations of life',[58] i.e. must contribute to significantly reducing a district's greenhouse gas emissions and to mitigating the effects of climate change.

According to the case law of the Higher Administrative Court of Schleswig (OVG Schleswig) and the Federal Administrative Court, this is assumed to apply not only in the case of local improvements (e.g. through a reduction in emissions from individual combustion plants), but also in order for the district heating supply to serve global climate change mitigation goals in accordance with the purpose of the ordinance.[59] It

54 (Buchmüller 2017).
55 § 17 GO Schleswig-Holstein.
56 § 109 GEG in conjunction with § 17 (2) GO Schleswig-Holstein.
57 The formal requirements in GO Schleswig-Holstein that are generally applicable to the enactment of ordinances must be observed.
58 § 17 (2) (1) GO Schleswig-Holstein.
59 While the OVG Schleswig still required a greenhouse gas reduction of 40% (OVG Schleswig, decision of 5 January 2005, ref. 2 LB 62/04, para. 79; BVerwG, NVwZ 2006, 690 (692)), the OVG Magdeburg recently only required more than a 'trivial effect' (OVG Magdeburg, BeckRS 2018, 13014 para. 53).

is therefore important that 'global climate change mitigation' is explicitly mentioned as the purpose in the district heating ordinance.[60]

– **Compulsory connection and usage is demonstrably suitable for global climate change mitigation**

It is also necessary for a relevant climate change mitigation effect (greenhouse gas reduction) to be produced that represents an improvement over the (continued) operation of individual heating systems by the property owners,[61] and for evidence to be provided that demonstrates the climate change mitigation effect associated with a central district heating supply.[62]

If this is the case, there is an 'urgent public need' for the enactment of a district heating ordinance if the district heating supply is cost-efficient, and its operation guaranteed, only if utilisation is high – due to compulsory connection and usage – as this is the only way that the district heating supply can also exert its mitigating effect on climate change.[63]

– **District heating supply by public institution**

In addition, the district heating supply must be operated as a 'public institution',[64] i.e. the district heating supply must be under municipal ownership and dedicated to a public purpose.[65]

The provisions of GO Schleswig-Holstein permit tasks to be transferred to private third parties, such as an energy supply company organised under private law, only if an operating agreement grants the municipality a strong influence (takeover, self-entry, co-determination and veto rights) over the district heating supply.[66] In the design of the operating agreement, the decisive factor is whether the municipality can also legally enforce its proposals against the private operator.[67]

– **Proportionality of compulsory connection and usage**

Because compulsory connection and usage infringes upon fundamental rights – in particular those of heat consumers residing in the area subject to the ordinance[68] – the

60 BVerwG, NVwZ 2004, 1131 (1131 f.).

61 OVG Schleswig, BeckRS 2005, 25866.

62 This evidence can be provided, for example, in the form of an expert opinion.

63 For a detailed discussion of this argument, see OVG Schleswig, BeckRS 2005, 25866.

64 § 17 (2) (1) GO Schleswig-Holstein.

65 (Dehn/Wolf 2019, p. 206).

66 (Dehn/Wolf 2019, p. 207).

67 OVG Magdeburg, BeckRS 2018, 13014, para. 26f.

68 Affected rights include the freedom of ownership established by Article 14 GG, the general freedom of action established by Article 2 (1) GG and – in comparison to properties not subject to the ordinance – the principle of equal treatment established in Article 3 (1) GG. There may also be an infringement on the occupational freedom protected by Article 12 (1) GG if energy producers and suppliers lose potential heat customers (e.g. natural gas customers with gas boilers) due to compulsory connecdistrict heating ordinance must, for reasons of proportionality, provide for transitional regulations for existing buildings,[69] general hardship regulations, and (limited) exceptions for more climate-friendly individual heat supplies.[70] § 17 (3) (2) GO Schleswig-Holstein also requires district heating ordinances to provide for transitional periods.

24.4.2 Enactment of a District Heating Ordinance Based on the GEG

Although it ultimately makes little difference whether the district heating ordinance is based on § 109 GEG or on § 17 (2) (1) GO Schleswig-Holstein, the main advantage of authorisation based on § 109 GEG is that, according to the case law of the Federal Administrative Court, it is considerably easier to demonstrate that compulsory connection and usage is suitable for climate change mitigation.[71] Rather than an expert opinion (see Section 24.4.1), proof that the district heating supply meets the requirements of § 44 GEG (formerly No. VIII of the Annex to the Renewable Energies Heat Act (EEWärmeG)) is sufficient evidence of the suitability for climate change mitigation. It is therefore advisable that municipalities in Schleswig-Holstein base provisions for compulsory connection and usage on § 109 GEG in conjunction with § 17 (2) (1) GO Schleswig-Holstein.

24.4.3 Tendering Obligations of the Municipality

If municipalities decide to enact a district heating ordinance, there may be tendering obligations arising from cartel law or public procurement law, depending on the form of the contractual relationships. Tendering obligations may pertain to:
– the granting of rights of way for the laying of district heating pipelines under public roads and paths (concession or permit agreement) and
– the operation of the district heating supply if a private party takes this over for the municipality (operating agreement).

tion and usage. Such interference can be justified, however, by considerations related to climate change mitigation.; (Kahl/Schmidtchen, 2013, p. 313).

69 It is clearly proportionate if existing buildings are only subject to compulsory connection and usage if the heating system is replaced voluntarily. (Hehn, 2015, p. 371).

70 In some cases, claims for exemption for particularly energy-efficient buildings are also under discussion; (Kahl/Schmidtchen, 2013, p. 321).

71 BVerwG, decision of 8 September 2016, ref. 10 CN 1.15.

24.4.4 Advantages and Disadvantages for Operators

For operators, the main advantage of compulsory connection and usage is that this requirement secures district heating sales. Because of this dominant market position, however, competition authorities monitor this situation especially carefully to protect against excessive pricing and abusive practices.[72]

In addition, the strict conditions for compulsory connection and usage significantly restrict the operator's economic freedom of choice.

A compulsory connection to district heating can also reduce acceptance of the heat supply among future district heating customers.

24.5 Key Findings and Outlook

This analysis of consumer integration into green heating networks produced the following key findings:

No obligations to purchase heat can be established at the level of urban land-use planning. However, the municipality can impose prohibitions and restrictions on the use of air-polluting substances for new and existing buildings (§ 9 (1) (23) (a) BauGB) and require property owners to take measures to promote the use of renewable heat when constructing new buildings (§ 9 (1) (23) (b) BauGB). In the case of existing buildings, it is always necessary to take into account the limitations prescribed in Article 14 GG for the protection of existing buildings. As a result, urban land use planning plays only a supporting role alongside other measures and has a limited steering effect.

The regulatory options available within the framework of an urban development contract go beyond what is possible with urban land use planning. With the help of this instrument, the municipality can establish requirements for a local district heating network, the connection to it, and the use of the heat from it (cf. § 11 (1) (2) (4) BauGB). However, it cannot force parties to enter into such a contract; the principle of freedom of contract applies. In practice, a contract is concluded only if it is of (economic) interest to potential developers and investors. In principle, urban development contracts can refer to climate change mitigation measures in new buildings as well as in existing buildings. It is particularly important that owners of existing buildings perceive there to be sufficient (economic) incentives to implement such measures, however, given the protection granted such buildings under building law.

Furthermore, a municipality can introduce a municipal ordinance (district heating ordinance) imposing an obligation to connect to and use district heating. All properties in the area subject to the ordinance must then meet their heating needs with district heating. In principle, this requirement applies to both new and existing build-

72 (Buchmüller 2017).

ings, though with restrictions for existing buildings due to the principle of proportionality. Municipalities in Schleswig-Holstein can base the enactment of district heating ordinances on authorisation granted by state law (§ 17 (2) (1) GO Schleswig-Holstein) or federal law (§ 109 GEG in conjunction with § 17 (2) (1) GO Schleswig-Holstein). The main advantage of compulsory connection and usage is that this requirement secures district heating sales; however, the operating agreement concluded with the municipality significantly limits the operator's economic freedom of choice. There is also a risk that the obligation will reduce acceptance of district heating among 'compulsory customers'.

Based on these findings, a combination of urban planning instruments that responds to local conditions appears to be a promising approach for integrating as many heat consumers as possible into the local heating network. A provision in the development plan prohibiting the use of certain heating fuels (§ 9 (1) (23) (a) BauGB) could, for example, be supplemented by a municipal district and heating ordinance. This would allow the municipality to control the heating fuels used and the connection to a heat network in the neighbourhood.

In Heide, the city in which the QUARREE100 research project is located, the City Council recently voted to exclude fossil fuel use from future development plans (§ 9 (1) (23) (a) BauGB).[73] This does not, of course, alter the fact that every development plan requires a case-by-case assessment. But the city of Heide has set itself the goal of becoming climate-neutral by 2045 and aims to adapt its urban land-use planning accordingly.

Furthermore, Rüdersdorfer Kamp in Heide, the neighbourhood that is to receive an upgraded energy supply in the course of the QUARREE100 project, is to be designated as an urban redevelopment area. This will allow access to urban development funds to finance the necessary redevelopment measures (§ 164a BauGB).

The introduction of a municipal district and heating ordinance is an instrument that the City of Heide will consider only if it proves to be economically necessary and reasonable.

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Lennart Winkeler, David Unland, Teike Scheepmaker,
Katrin Fahrenkrug, Torben Stührmann

25 Development and Basic Conceptualization of Digital Decision Support Tools to Promote Participation Processes in Energy Transition

Summary: The influence of humans on the emergence of the Climate Crisis has been scientifically proven for a long time and comprehensively clarified once again within the context of the current IPCC Report, with Greenhouse Gases, first and foremost Carbon Dioxide, once again being demonstrated to play a central role. (IPCC 2021) Since the Paris Agreement, there has been political consensus to limit Global Warming to a maximum of 2° C compared to the pre-industrial era. (UNFCC 2015) Existing societal consumption patterns and complex, heterogeneous decision-making structures complicate the necessary design of novel technical systems for the energy transition and may result in unexpected opponent behaviors. In examining the role of such behaviors in energy system transformation, Agent-Based Modeling (ABM) offers the possibility of looking at specific social dynamics. To ensure broad access for stakeholders and to increase their acceptance, models and results must be designed in an actor-specific and interactive way. In doing so, participatory processes are promoted as the motivation to participate is increased. In the following book chapter, a system for the conceptualization and development of digital participation platforms using ABM is presented, which aims to connect and process the complexity of techno-economic and socio-technical processes with the help of transdisciplinary methods, so that stakeholders of the energy transition can interact with them on the neighborhood level.

25.1 Introduction

The Climate Crisis and the undoubted human influence on it strongly demand a systemic change, which can only be implemented through profound changes in industry and society. Otherwise, country-specific greenhouse gas budgets will be depleted in a

Lennart Winkeler, Fachgebiet Resiliente Energiesysteme, Fachbereich Produktionstechnik, Universität Bremen

David Unland, Torben Stührmann, University of Bremen, Faculty 4 Production Engineering, artec Sustainability Research Center, Department for Resilient Energy Systems

Teike Scheepmaker, Katrin Fahrenkrug, Raum und Energie, Institut für Planung, Kommunikation und Prozessmanagement GmbH

https://doi.org/10.1515/9783110777567-025

few years. (IPCC 2021) Solutions need to be thought of in both the long and short term, in a socially just and international way. For example, Germany is aiming for 65% less CO_2 equivalents[1] by 2030, 88% less CO_2 equivalents[1] by 2040 and climate neutrality by 2045. (Federal Republic of Germany 2021) Thus, the transformation of industry, society, energy production, infrastructure, transport and others is subject to enormous pressure, which creates additional uncertainties in implementation. The concept of resilient transformation of urban spaces addresses these uncertainties by creating adaptive socio-technical capacities for adaptation.

Private households are key drivers of system transformation, as their behavior in relation to energy issues has the potential to both actively contribute to decarbonization and intensify its deceleration. (Dubois/Sovacool/Aall et al. 2019) Therefore, aspects of acceptance as well as knowledge and lifestyles must be considered alongside technological and infrastructural changes, to develop sustainable solutions to the Climate Crisis. (Stoknes 2014, Creutzig/Roy/Lamb et al. 2018)

The results presented below were developed as part of the BMBF project *QUARREE100,*[2] focusing on exploring and developing participation, acceptance, and transfer in energy transition processes. The aim was to support the determination of the economically, ecologically and technically optimal design of the overall concept of a neighborhood with "nearly zero emission buildings". Thereby, a further object was to integrate and support actors from civil society in the development and implementation of the concept through an active consultation process. For this purpose, an early dialogue program was initiated to balance objectives and associated conflicts. Since the subject of the study is a built-up neighborhood, the active role of the residents is a constitutive element in the planning and implementation phase of the project. The neighborhood at Rüsdorfer Kamp described in chapter 22: „QUARREE100 – Resilient, integrated, system-serving and sustainable energy supply systems in existing urban quarters in the context of regional structural processes" is characterized by a heterogeneous infrastructural and social settlement structure. The implementation of the corresponding energy concept is therefore accompanied by challenges, which have a strong influence on the transformation speed of the neighborhood and the efficiency of the energy system. Considering the acceptance of the residents and the creation of formats for participation in the development process can be crucial for success. This is because the concept uses decentralized prosumer approaches and the connection of individual households to a new energy system can determine its success or failure. The combination of modeling and decision-making environments can be used to improve the monitoring and provision of modern empowerment platforms.

1 Compared to emissions from the reference year 1990.
2 QUARREE100: https://quarree100.de/.

25.2 Simulation Tools for Meeting Challenges in the Energy Transition

Direct CO_2 emissions, which resulted from household energy supply in 2016, accounted for nearly 11% of global carbon dioxide emissions. (World Resources Institute 2019) In contrast, for example in Germany, a slight decrease in emissions of about 5% can be identified between the years 2005 and 2018. (German Federal Statistical Office 2019a) This can be seen as an effect of efficiency and consistency measures. However, this reduction is counteracted by trends toward increased equipment levels and larger living space per person. (German Federal Statistical Office 2019b) For a holistic view of the influence of households on greenhouse gas emissions, the industrial processes demanded by consumer behavior, the associated logistics, private transport, and food as well as infrastructure must also be considered. To minimize the remaining CO_2 budget for the necessary achievement of the Paris Climate Agreement goals and thus prevent irreversible climate impacts and tipping points as well as consecutive economic damages, for the avoidance of emissions "the sooner the better" applies. (Cai/Lenton/Lontzek 2016) The rates of new construction and modernization (of the existing housing stock) as well as the associated policy goals are demonstrative of the direct influence of households on the climate crisis through (in-) efficient housing. A study by the German Federal Environment Agency (2019) indicates a share of 35.9% unrefurbished and 51.4% partially refurbished residential buildings – according to the study, only 4.3% of buildings in Germany achieve the status of "fully refurbished," while the remaining 8.4% are assigned to new construction. (Metzger/Jahnke/Walikewitz et al., 2019, p. 76) The annual refurbishment rate is assessed to be approximately one percent. (BMWi, 2014, p. 5)

A targeted doubling of the renovation rate of the German stock by 2030 (BMWi, 2019, p. 34), which results from the European requirement of the "Long-Term Renovation Strategy" (EU 2018) from the Climate Protection Act (Federal Republic of Germany 2021), has not yet been implemented despite numerous funding instruments. (dena 2021) This highlights the problem – the role of residents is crucial, provided that strong regulatory implementation measures are waived and an acceptance-oriented design of the transformation in the building sector is favored politically. (Steg/Perlaviciute/van der Werff 2015, Chadwick/Russell-Bennett/Biddle 2022) Consequently, the challenge is not only the development of novel technical concepts, but also the acceptance by the society as well as adoption rates of the concepts. (BMWi, 2014, p. 5) This underlines the reference to theories of socio-technical transition research (Ahrens/von Gleich/Lißner 2002, Fichter/Noack/Beucker et al. 2006, Geels 2006; 2011, Stührmann/von Gleich/Brand et al. 2012) and innovation research (Bass/Krishnan/Jain 1994, da Silva/Uturbey/Lopes 2020). To develop a sustainable structure of energy systems within a built-up neighborhood and thus to guarantee a success of transformation processes, social acceptance by the residents must be taken into account. (Wachsmuth/Petschow/Brand et al. 2015) Additionally, there are techno-economic aspects, such as improving the savings potential of heating networks, which goes hand in hand with an increase in the connection rate on the part of the users.

In general, the simulation of systems offers great potential for identifying influencing factors, testing and designing different parameters and investigating different scenarios. This applies to both socio-technical and techno-economic research paradigms. In the following, a system for developing a platform that combines the previously mentioned elements is presented. A Stakeholder and Social Network Analysis will be designed and first steps for the creation of a theory-based and empirically supported model will be presented. Through this, challenges of further development and differences between pure research and application models are revealed.

25.3 Transdisciplinary Combination of Methods

Linear optimization models are often used for techno-economic simulation of systems or their components *(see also chapter 27 "Resilient Energy System Design of Low Emission Districts – A Model Chain from National Scenarios to Plant Operation").* The method is used within various research fields of the energy transition. (Hilpert/Kaldemeyer/Krien et al. 2018, Krien/Schönfeldt/Launer et al. 2020, Schnuelle/Wassermann/Fuhrlaender et al. 2020, Wassermann/Schnuelle/Kenkel et al. 2020, Röder/Meyer/Krien et al. 2021) For socio-technical considerations, ABM is an often-used approach. It is also spread across different areas for investigating the transformation of energy systems. (Hicks/Theis/Zellner 2015, Rai/Robinson 2015, Alyousef/Adepetu/de Meer 2017, Busch/Roelich/Bale et al. 2017, Marcucci/Le Pira/Gatta et al. 2017, Schnuelle/Thoeming/Wassermann et al. 2019, Halwachs/von Streit/Knoeri 2020, Schnuelle/Kisjes/Stuehrmann et al. 2020) In order to make these tools accessible to a broad range of stakeholders, open-source provision of the models must be ensured. (Pfenninger/Hirth/Schlecht et al. 2018) In addition, the effectiveness of these tools in terms of their applicability and interactive capabilities are to be investigated, thereby strengthening participatory structures. (Fiukowski/Müller/Förster 2019, Deckert/Dembski/Ulmer et al. 2020)

The advantage of ABM lies particularly in its ability to simulate interacting entities, such as heterogeneous stakeholder groups in transformation processes. This allows needs, decisions, and behaviors to be processed in a way that can be experienced, studied, and explained. (González-Méndez/Olaya/Fasolino et al. 2021) However, many models simulate behavioral changes of individuals and households only in a rudimentary way, often using the "Rational Choice Theory". (Hechter/Kanazawa 1997) This theory assumes decision behavior to be mainly economically motivated and supposes seamless knowledge and perfect information acquisition with perfectly balanced markets. For a realistic consideration of human decision behavior in simulations, the application of social psychological theories can be used. (Schlüter/Baeza/Dressler et al. 2017) One of the main challenges in simulating social elements, is to make these theories computationally explicit, thus translating theoretical notions into algorithms that can be encoded into the behavioral rules of a simulated agent. (Ernst 2010)

For the creation of the model, which serves as the basis of the described interactive participation platform, the simulation of the possible behavior of households in the studied neighborhood is replicated using the "Theory of Planned Behavior" (TPB). (Ajzen 2002) It is suitable for representing relative behaviors, i.e., those in which an individual opinion towards the corresponding action is to be performed. The basic components are *Attitude*, *Subjective Norm*, and *Perceived Behavioral Control* toward the particular behavior, which result in the intention to perform the particular action. (Ajzen/Fishbein/Lohmann et al. 2018) To integrate the TPB in an ABM, surveys are conducted to determine the residents' attitudes toward specific environmentally relevant behaviors. The goal is to empirically establish a basis by which decisions and influences on (energy) systems can be mapped. (Niamir/Filatova/Voinov et al. 2018) For the initial decomposition of the social neighborhood structure into its components, a stakeholder analysis according to (Reed/Graves/Dandy et al. 2009) is conducted. On the one hand, this serves to inventory and prioritize the elements that are to be transferred from the real neighborhood to the simulation neighborhood. On the other hand, the awareness about key players and normal actors can also be used for the practical support during the first project phase. Here, the actors are first identified in order to distinguish and categorize them afterwards. The agents take on the role of households in the neighborhood. Since the interaction between them is an essential part of the dynamics of the model, their network behavior is additionally investigated to give the targeted platform a realistic basis, which can be explored by users in a comprehensible way. Since a network structure fosters collective behavior and self-organization and furthermore provides information about the social capital of agents, this part should not be based on rudimentary assumptions. (Will/Groeneveld/Frank et al. 2020) The ODD *(Overview, Design Concepts, Details)* protocol will be applied to document the ABM (Grimm/Railsback/Vincenot et al. 2020) so that continuation, replication, and tracking are assured.

The application of simulation in the context of stakeholders, such as in participatory processes, opens up an interface that cannot be ignored. Participatory modeling is considered an experiential learning process in which attention, knowledge and motivation as well as ideas of stakeholders are merged to jointly create and discuss scenarios of reality. (Voinov/Jenni/Gray et al. 2018) This provides a simple way to communicate and understand the complexity of future sustainable systems. (Beers/Veldkamp/Hermans et al. 2010, Mößner 2018) Additionally, the collective and social learning experienced in this process can significantly improve the resilience and adaptivity of communities. (Henly-Shepard/Gray/Cox 2015) The term *Decision Support Systems* (DSS) (Power 2002) is used to describe tools that are used to explore and simulate complex processes of various disciplines. They help illustrate visionary sustainable images (John/Keeler/Wiek et al. 2015) and reduce complexity for outsiders, policymakers, and administrators

(Deckert/Dembski/Ulmer et al. 2020) *(Example: Arizona Decision Theater*[3]*)*. Modern digital media solutions offer a wide set of possibilities to enhance the experience, while using such systems. John/Lang/von Wehrden et al. (2020) therefore propose to extend the terminology to *Decision Visualization Environment* (DVE). Here, transformative interaction is established between humans, computers, and content through the application of semi-immersive environments coupled with a strong visualization component *(Example: CityScope*[4]*)*. Direct, multimodal and natural interaction with digital media can help people grasp abstract concepts better (Jacob/Girouard/Hirshfield et al. 2008) and simplify access to complex problems (Shneiderman 1982).

The previously described transdisciplinary methods are linked by a systematic approach to develop Agent-Based Modeling of socio-technical systems. (van Dam/Nikolic/Lukszo 2012) The following chapter specifically addresses the procedure and explains the individual components as well as the results of the implementation of the first stages.

25.4 Procedure and Results of the Creation of Agent-Based Modeling

The Agent-Based Model is used to study household decisions influencing the energy transition and simultaneously constitutes the backbone of a digital, interactive participation platform. For its creation, a ten-step procedure is applied, which leads to a systematic, tested development. (van Dam/Nikolic/Lukszo 2012) The ten steps consist of *(1) problem formulation and actor identification, (2) system identification and decomposition, (3) concept formalization, (4) model formalization, (5) software implementation, (6) model verification, (7) experimentation, (8) data analysis, (9) model validation, and (10) model use*. In the following section, the first three stages, i.e., the conceptualization and the basis for building the model, are presented.

Stage 1 – Problem formalization and actor identification: At the beginning of the model creation, a definition of the underlying problem is provided. It is divided into two major parts: First, the strong yet commonly neglected influence of neighborhood residents on the transformation process and its time horizon will be examined. Secondly, the increase of the stakeholders' motivation to participate in the transformation process is considered via interactive participation methods, which is why the model must be transferable and provide interfaces for interaction. Therefore, the research focus lies especially on the households' acceptance and motivation for participation in residential energy transition processes. The participation work and social

3 https://dt.asu.edu/.

4 https://cityscope.media.mit.edu/.

psychological processes evoke emergent patterns and tipping points, which are of particular interest, as they have a direct impact on the implementation possibilities of novel energy systems. Here, it is investigated whether there are elements beyond monetary reasons that can serve as incentives to use renewables over fossil fuels.

This is based on the initial hypothesis that the attention for acceptance and the enhancement of it through participation processes be elementary components for the implementation of novel concepts with a decisive influence besides the classical economic factors. The problem under investigation extends both on the scope of overall societal challenges to cope with the climate crisis as well as on the stakeholder level. For households or energy suppliers, the focus is often set to micro-level socioeconomic issues.

Stage 2 – System identification and decomposition: The smallest time step considered in the model was set to one day. The longest relevant step extends from the year 2020 to 2045. For the inventory of the socio-technical components, a stakeholder analysis was performed according to Reed/Graves/Dandy et al. (2009). In this process, agents, objects and their environment are sorted and the corresponding states and properties are assigned. The techno-economic components are derived from the energy concept, which was created in the *QUARREE100* project. Figure 25.1 depicts the results of the identification and spatial sorting of stakeholders. The center of the graph represents the neighborhood while the geographic distance increases towards the margins of the image. The identified stakeholders are divided into seven categories explained below, which in turn are divided into subgroups (graphically represented as units of the given category; subgroups are subject to spatial reference within the graph). The results show that, next to the residents, the commercial sector (a subsection of Economy), is a relevant component within the neighborhood, with a total amount of 13 units. Other components in the vicinity of the neighborhood are companies of the energy industry, planning offices, business associations and housebuilding. Politics and administration are mainly located in the surroundings of the city of Heide and consist of the city administration, political groups as well as committees and advisory boards. Cultural aspects from associations and initiatives are partly represented in the neighborhood but are mostly found outside of it. Despite their small number, the influence of these entities in the neighborhood is rated as strong. Social institutions such as churches and educational institutions are only marginally present. Media and research are represented in comparatively small numbers and are mainly located in greater distances.

The results of the stakeholder analysis suggest that the targeted stakeholders comprise households, businesses and politics. Most actors are located in these groups, which becomes plausible when focusing on a residential neighborhood. Thus, the analysis focuses on the households and the operator of the local energy system but neglects the commercial entities of the neighborhood. This delineation is made to more explicitly address the research question of investigating the influence of residents to transform energy systems of built-up neighborhoods. The focus will be on modeling socio-technical dynamics at the level of household decisions, as these have a

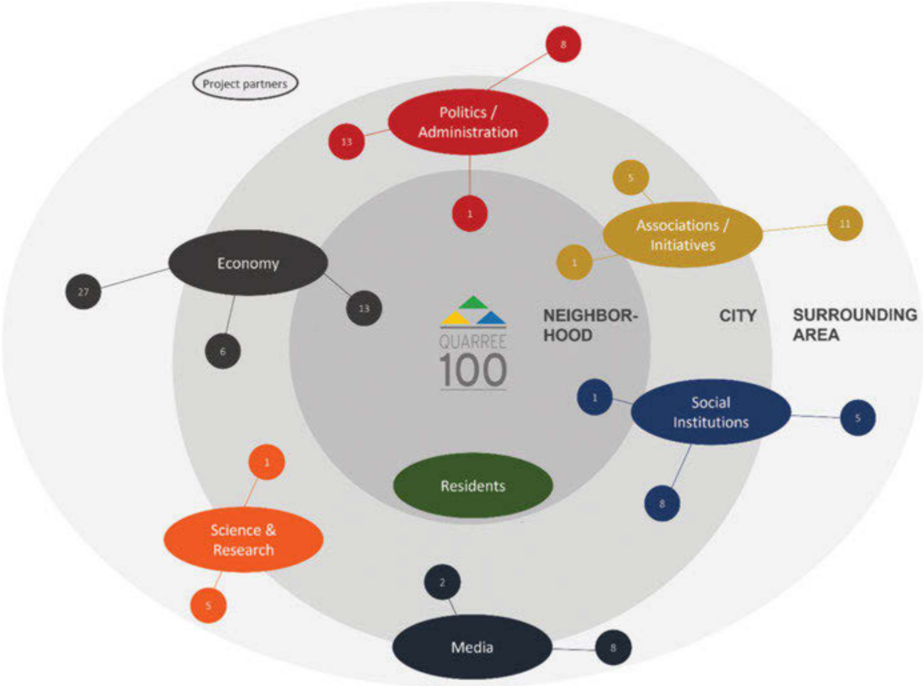

Figure 25.1: Spatial sorting of the stakeholders active in the QUARREE100 project as identified by the means of a stakeholder analysis. The center of the graph represents the neighborhood while the geographic distance increases towards the margins of the image. Subgroups are shown as units of the stakeholder categories and have spatial reference. (Source: own representation).

significant influence on the degree of neighborhood transformation and the connection rate to a new type of energy system. If the framework is expanded to include the commercial sector, further fields of action of individuals should be taken into account, since an expanded economic interest of stakeholders could arise and a mixing of categories could occur. Therefore, the category of the commercial sector is not considered further in the surveys described below and should be examined more closely in a further development of the basic model. The households are represented as agents in the model. The energy system itself and the inhabited infrastructure are represented as technical objects. Dynamics of the energy- and financial market as well as political factors are part of the model's environment. Agents, in the ABM sense, represent entities that can make "their own" decisions, while objects do not have an autonomous structure. The environment is the domain that contains the considered agents and objects and that is framed by the system boundaries.

Stage 3 – Concept formalization: The theoretical basis of the model is complemented with neighborhood-specific real data from a socio-psychological survey, under consideration of behavioral components on decision-making (after Niamir/Filatova/Voinov et al.

2018). This method focuses on the knowledge and awareness of the participants about the impact of the Climate Crisis on economic developments and sustainable energy use. Furthermore, norms related to climate-friendly behavior are queried and data on energy-efficient habits as well as factors influencing personal behavioral changes are collected. General socio–economic and demographic data are also included, such as employment and housing status, and assignment to income groups. The data were ranked on a Likert scale of 0–7. Participants of the survey were the residents of the neighborhood Rüsdorfer Kamp. The combination of the socio-psychological data of the households in the neighborhood with the techno-economic data of the energy concept as well as existing GIS-data requires the consideration of ethical and legal standards. To comply with these, the data are anonymized and randomly distributed in the model to allow general inferences to be made about the neighborhood, but not about individuals. This approach enables the applicability of the model and subsequent use of it within a DVE. Results of the survey are not elaborated within the scope of this work, since the overview of the approach and overall conception as well as the highlighting of the novel combination of interdisciplinary methods are focused on.

Based on a utility-based decision algorithm and the beforementioned data base, the TPB's concept of household decision making is applied. The simulated actors in the base model can choose one of three actions per action step: Efficiency actions (investing in an environmentally relevant technology for heat supply), consistency actions (switching electricity suppliers), or sufficiency actions (adjusting their own behavior). Figure 25.2 schematically depicts the process and the associated influences on the decision-making simulated in the model.

The intention of households to make environmentally relevant decisions increases with a positive attitude towards the associated behavior. In addition, this intention increases with the subjective norm, i.e., the belief that relevant others expect the household to behave in a certain way. Furthermore, the intention increases when the agents are aware that the behavior is not challenging or that it is easy to deploy. The utility-based decision algorithm, adapted from the Bench model of (Niamir/Filatova/Voinov et al. 2018), simulates the user behavior. To calculate the attitude of households, the average of the following values is considered and normalized to the Likert Scale: A_k (Climate Energy Economy Knowledge), A_e (Climate Energy Economy Awareness) and A_d (Energy Decision Awareness). The same is done for the Subjective Norm (N_s) and the Perceived Behavioral Control (B_i). These values can be influenced by agent interaction (i.e., household communication) and by emerging behavioral feedback loops.

Whether a particular behavior will be performed or not is calculated by the equation $U_t = \alpha^* C + (1-\alpha)^* E + A + N + B$, where U_t corresponds to the utility value of the corresponding behavior in the current time step, α is the household's average share of expenditure on energy with respect to its total expenditure, E represents the household's actual expenditure on energy, and C describes the overall expenses for other goods. Agents choose the behavior, which produces the highest utility value compared to U_{t-1}.

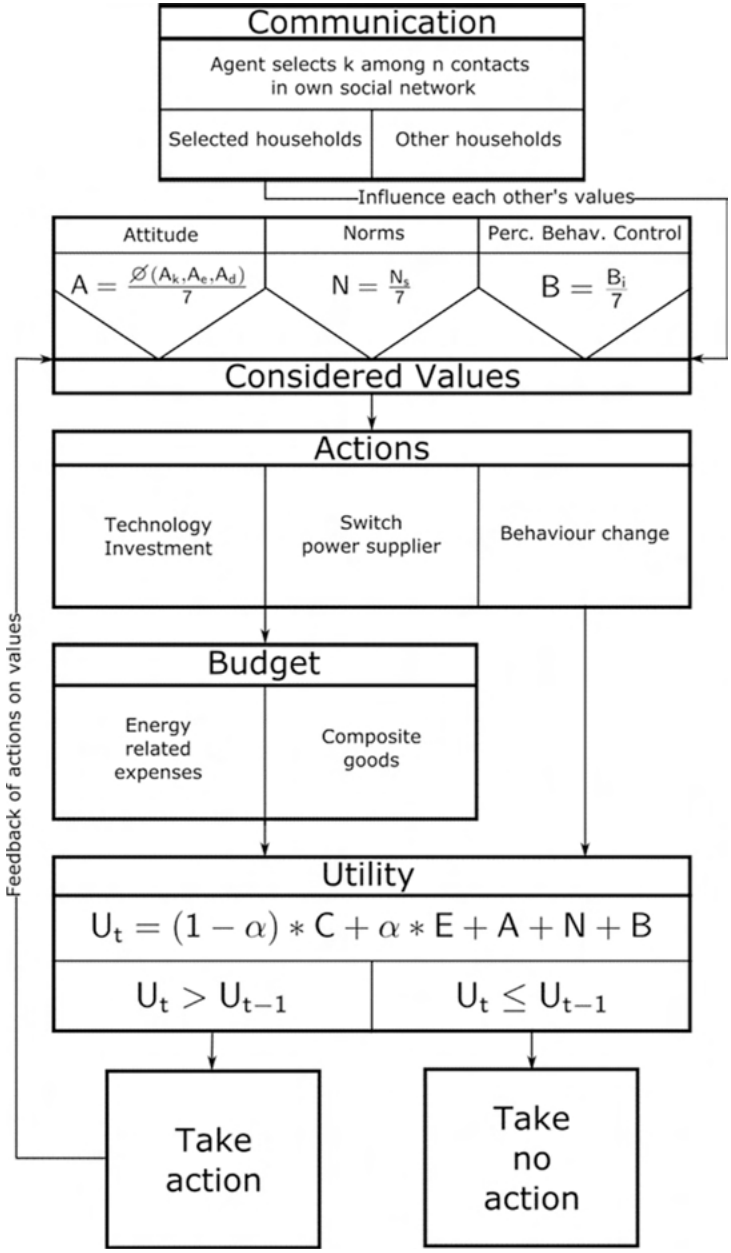

Figure 25.2: Schematic flow of action and interaction of household agents according to a theory-based social-psychological foundation (Source: own representation).

For the implementation of the interaction between households, a network analysis is conducted according to Will/Groeneveld/Frank et al. (2020). The authors emphasize that the direction of interaction within a network is of great relevance, hence, both a unilateral influence by the performing agent and mutual influences between two contacts are considered for the implementation of the network function. The analysis is defined as an agent-centric analysis with exogenous structure. The network activity for analysis and implementation is partitioned into three dimensions. *(a)* Households are clustered by employment status to distribute the network data. *(b)* The number of household contacts is divided into spatial dimensions by street, within neighborhood-internal, and -external. *(c)* The number of contacts per time step is defined by daily, weekly and occasional frequency. In the basic model, no further dynamic development of the network is done, which is why the degree of institutionalization, homophily, reciprocity, and transitivity are not taken into account. The intensity of an influence of further specific aspects (e.g. cultural) on the socio-technical dynamics is not further elaborated within the scope of this model. However, the basic model can be extended to examine and explore various aspects in more detail that could also have an influence on neighbourhood development.

The household communication shown in Figure 25.2 is based on the survey, where *n* corresponds to the general number of contacts at the spatial level, and *k* represents the number of contacted households in temporal terms.

Stage 4 – Model formalization: To implement this stage, pseudo-code is formulated based on the concept for the translation of the scheme into computer-readable code *(Stage 5)*. Following this, further stages formulated above are carried out, which include the verification of the desired operation of the model *(Stage 6)*, the performance of experiments *(Stage 7)*, the analysis of the simulated results *(Stage 8)*, as well as the model validation *(Stage 9)* and finally the usage of the model *(Stage 10)*.

25.5 Conclusion and Outlook

The described approach aims to create an environment based on *Geographic Information Systems* (GIS) where agents move and act inside a spatial landscape, which represents the built-up neighborhood *"Rüsdorfer Kamp"* studied in the project. Although GIS are generally not particularly well suited for dynamic modeling, the combination of ABM and GIS offers unique advantages. (Crooks/Castle 2012) This makes using this feature elemental in order to achieve the best possible level of interactivity for a reflexive participatory platform in terms of a DVE. Castella (2009) found increased emotional interaction and discussion during collective operation of the tool when providing realistic renderings of the environment. As a result, the discussion was moved to a micro level and away from a holistic consideration of systemic dynamics. (Castella 2009) Tuler/Dow/Webler et al. (2017) describe the combination of participation and modeling as an effective way to bring stakeholders together and organize information about complex systems through these tools. For further developing of the described concept and transferring the resulting model, an interactive tool based on the CityScope approach developed by MIT Medialab is deployed. (Alonso/Zhang/Grignard et al. 2018, Grignard/Macià/Alonso et al. 2018, Orii/Alonso/Larson 2020) This digital platform uses tangible objects. In combination with the modeling environment GAMA[5] (Taillandier/Grignard/Marilleau et al. 2019) it enables participatory modeling (Figure 25.3).

Figure 25.3: Prototype of an interactive participatory platform for energy transformation research using the MIT Medialab CityScope approach (Source: Own representation, © Matej Meza).

When simulating complex systems, the *KISS* paradigm *("Keep It Simple Stupid")* should be considered. (Grignard/Taillandier/Gaudou et al. 2013) In collaboration with stakeholders, the degree of realistic representation plays a major role, too – oversimplifications could reduce the motivation of participants. Modelers therefore need to find the right path between detail and abstraction when designing a DVE as participatory support of transformation processes. High-quality participatory processes can have a positive impact on people's attitudes, while a bad design can have a negative impact – and eventually lead to skepticism and even rejection. (Wiek/Ness/Schweizer-Ries et al. 2012)

An approach like the one presented here was used by Pagani/Shinde/Hellweg et al. (2019) for the creation of an agent-based model to study housing choice decisions by households. The study focuses on the model development for the investigation of the specific behavior of agents and the dynamics between them. The methodology presented in this chapter follows an additional purpose: It describes the development

5 GAMA: https://gama-platform.github.io/.

of a basic module to establish an interactive exchange between stakeholders and research models. At the same time, the influence of the module on the participants' attention towards and knowledge about the topic under discussion is investigated, to facilitate the systematic generation of incentives and to motivate participation in the energy transition.

Empowering households to exert a strong and active influence on transformation processes supports the management of a sustainable development and technical solution approaches. (Ornetzeder/Rohracher 2006, McMeekin/Southerton 2012, Schot/Kanger/Verbong 2016) The application of modern, participatory tools will play a decisive role in this context. The described approach can be used as a guideline to develop such novel tools in an interdisciplinary, holistic way. The support of the much needed monitoring of the energy transition in existing buildings could be given an effective and tangible component and the motivation to participate in and accept the transformation could be strengthened. The described approach also supports the systematic transfer of pilot projects to other neighborhoods and the necessary comparability. Future research will show to what extent the further development and application of the DVE, which has been realized with the help of the described conceptualization, has an influence on the implementation process of a novel energy system in the context of the QUARREE100 project investigation.

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Volker Binding, Wolfgang Braun, Janko Röbisch

26 Stochastic Modelling and Economic Analysis of Systems for using Volatile Solar Power

Summary: In this document, a generic model approach for considering volatility in the dimensioning and economic analysis of systems for using volatile solar power is presented. The individual model components such as weather conditions, operating costs, electricity price, etc. can be defined separately in the sense of a flexible toolbox, put in relation to each other and the future development of the system may be simulated in the form of a common distribution. Each model component can contain both deterministic and stochastic components, which affect the overall system through the connection of the individual model components. The toolbox thus is not limited to be used in the context to the project QUARREE 100, but may be used in different environments and circumstances.

In this demonstration, it is now shown as an example how the volatility of weather is translated into energy flows and cash flows via the energy production of the photovoltaic cell and the self consumption and marketing of the electric flow and the regional economic effects. It is shown in principle how the individual model components interact. The individual model components are deliberately kept simple in this demonstration (constant load profile, constant electricity price, constant Capex costs, etc.). In this demonstration, only the weather is modelled with a deterministic, seasonal component and a stochastic component. The geometries of buildings from the Rüsdorfer Kamp, Heide, were used to consider the effects of dynamic weather conditions on photovoltaic systems (size of the roof area, roof pitch, orientation of the roof area).

The model presented here was implemented in the RealEstimate® software and is ready to carry out a specific investigation for the Rüsdorfer Kamp in a next step with a combination of dynamic weather, dynamic load profiles, dynamic energy price models and dynamic cost models.

26.1 Introduction

The use of regenerative energy sources will make a significant contribution to the energy transition and thus help to slow down or stop climate change in the long term. In addition, extensive independence from fossil energy sources creates greater political independence at national and European level.

Volker Binding, Wolfgang Braun, Janko Röbisch, Volker Binding, Tachycon GmbH, Hofholzallee 63, 24109 Kiel, Germany

https://doi.org/10.1515/9783110777567-026

Renewable energy sources such as wind or solar energy are usually subject to volatilities on different time scales (long term components, seasonal components, intraday components). Thus, the generation of solar energy cannot be arbitrarily adapted to the required energy demand. Secured financing is a prerequisite for the sustainable implementation of the results and thus for the energy and climate policy goals of the federal government.

Using a quantitative stochastic model, this study examines options for harmonizing energy supply and demand. For this purpose, the generation of volatile solar power is described using a stochastic weather model. The use of storage elements is included in the analysis. Subsequently, an economic feasibility analysis of different approaches is carried out using buildings in the Rüsdorfer Kamp as an example. Different funding options are considered. Finally, the impact of the construction and operation of a regenerative energy system on the region is quantified in terms of regional economic effects.

A legal, fiscal, social or political assessment of the topic is not intended and will not be made in this article. All relevant representations are to be understood purely as examples.

The modelling was carried out in the commercial software framework RealEstimate®. In RealEstimate® (macro)economic models, business models, weather models and other flow descriptions can be flexibly implemented and related to each other and solved using Monte Carlo methods (stochastic simulation, e.g. Stein/Braun/Villà et al. 2014). Different aspects (risk level, profitability, etc.) are analysed and evaluated (distributions in the target values, (stochastic) key figures, scenarios and sensitivities).

This article uses results of Tachycon's work in the project „*Resiliente, integrierte und systemdienliche Energieversorgungssysteme im städtischen Bestandsquartier unter vollständiger Integration erneuerbarer Energien – Rüsdorfer Kamp (QUARREE100): Städtebauliche Bestandsintegration und Mobilität: Erforschung regionalökonomischer Effekte und Geschäftsmodellanalyse*".

26.2 Modelling

The modelling in RealEstimate® includes the description of different model components that are related to each other (see Figure 26.1): A stochastic electric power generation is simulated from the modelling of the volatile weather conditions and corresponding energy-generating systems. The simulated electrical energy can be used in the model to satisfy load profiles, to feed into the grid or to operate an electrolysis. Electric storages can be integrated into this analysis. These stochastic electric flows are transformed into stochastic cash flows using electricity price models or remuneration models.

An example for a profitability analysis is carried out in Section 26.3. For this purpose, the model components of weather modelling, market modelling, modelling of energy-generating systems and financing are included in an analysis using the example of objects in the Rüsdorfer Kamp solar cadaster. This section demonstrates a method, how the conditions can be analysed under which the use of volatile solar energy could be economically interesting for residents in the Rüsdorfer Kamp under the regulatory framework conditions applicable at the time of planning.

Section 26.4 describes the implementation of a regional economic model in RealEstimate®, which is consistently based on the stochastic modelling of the cash flows. This allows investments and new business models to be analysed not only in terms of risk, return and other key figures from the perspective of the operator or investor, but also from a regional economic perspective. In this way, the effects for the Heide region and other regions can be analysed.

26.2.1 Model Component Climate and Weather

RealEstimateML (RealEstimate UG 2021) can be used to implement stochastic models for describing climate and weather. Solar radiation, wind strength or direction or other influences can be modelled in this way, both on a short time scale (weather) and on a long-time scale (climate). The uncertainty in future developments can be described by one or more stochastic components.

In this simple demonstration case, solar radiation is simulated on a whole day basis over a period of 30 years. The seasonally variable component of the radiation is described by a sine function. The overclouding is described by a stochastic component (see Figure 26.2). This results in the following equation for the daily yield:

$$E_{day}(t) = P(t) \cdot \frac{E_{spec}}{365} \cdot \frac{W(t)}{W_{avg}} \cdot X(t) \qquad 26.1$$

$P(t)$ is the peak power of the system, taking into account an annual decrease in efficiency, E_{spec} is the specific yield of the system, $W(t)$ is the seasonal dependence of the specific maximum yield

$$W(t) = W_{min} + \frac{W_{max} - W_{min}}{2}(1 + \cos(2\pi t + \phi)) \qquad 26.2$$

with $W_{avg} = (W_{min} + W_{max})/(2 \cdot EV[X])$ and $X(t)$ the weather dependent daily rate of return. The specific yield takes into account the location and orientation of the system as well as the climate at the site. The variation of $W(t)$ depends primarily on the geographical latitude of the site.

The intraday usage rate is represented by a deterministic function:

$$1 - \exp\frac{load\ profile}{1.5 \cdot (amonunt\ of\ energy)} \qquad 26.3$$

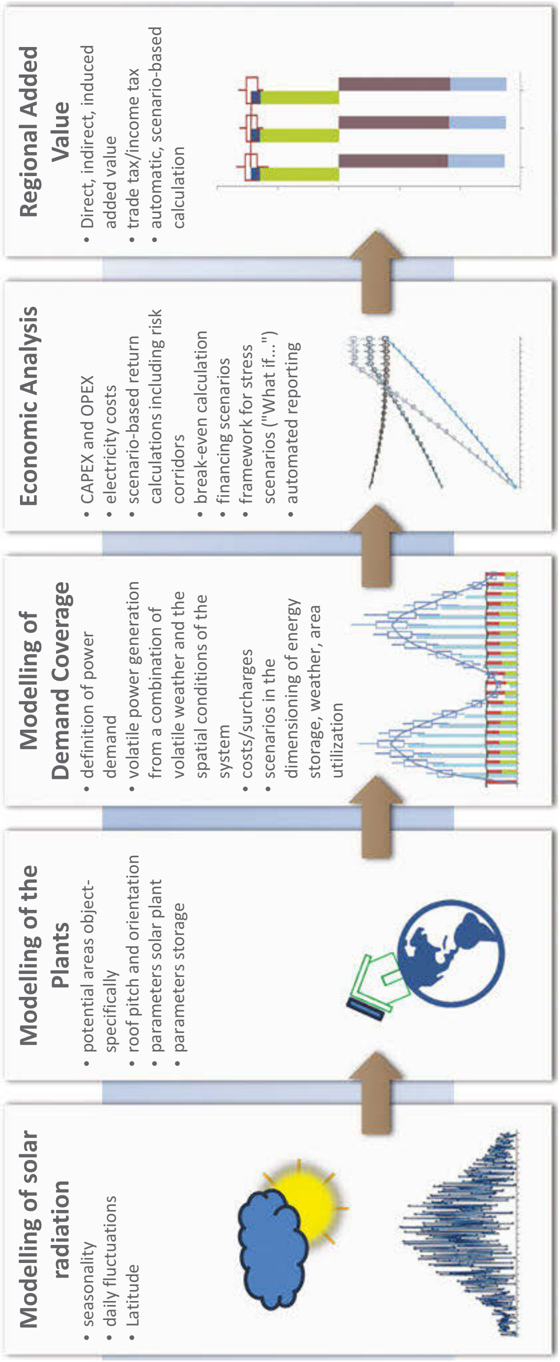

Figure 26.1: Schematic representation of the model in the software RealEstimate®.

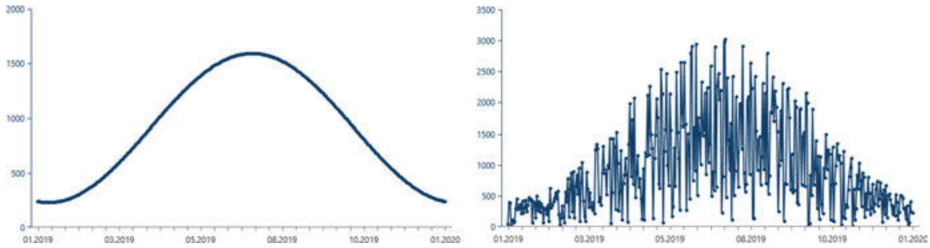

Figure 26.2: Modeling of seasonality and stochastic daily fluctuations in RealEstimate®.

This formula was found heuristically based on certain overclouding assumptions, and assumptions regarding timing mismatch between load profile and electricity production. The stochastic and seasonal electric current modelled in this way is used as input for the further model components. The volatility of the weather is thus transferred to the distribution of income from the sale of electricity (direct functional influence of the weather in the cash flow modelling of the value chains).

26.2.2 Model Component Solar Plant (PVA)

As an example, in our approach, the solar plant is assumed to have a net purchase price of € 1200 per kWp (kilowatt peak). After the observed period of use, the residual value of the system including disposal costs is set at € 0. We assumed the operating costs to be constant (30 €/kWp p. a.).

The physical properties of the system can be incorporated into the coupling of the energy conversion to the weather/climate model. In our example, we have assumed a solar plant with a specific generation of 1,000 kWh/(kWp*year). It is also assumed that the peak power of the plant decreases by 0.3% annually.

Consequently, the modelled system serves to transform a natural fluctuating and seasonal energy flow (solar radiation) into a fluctuating and seasonal electric current.

26.2.3 Model Component Load Profile

Deterministic and stochastic dynamics of load profiles can be described in this model component for describing load profiles. In the toolbox, these dynamics can also be linked to the dynamics of other model components (e. g. to the dynamics of weather events). As an example, in our simple demonstration case, we focus on the impact of seasonal, stochastic weather events on the overall system. Therefor we choose a constant load profile. With the integration of the load profile in the description of the value chain, an energy sink is introduced into the model system. By specifying system parameters of other model components (e.g., storage type, storage dimensioning, dimensioning of the power-generating systems), the target values in the load profile can be controlled, taking into account other target values such as the profitability of the overall system and non-controllable variables such as electricity price development and weather conditions.

26.2.4 Model Component Storage Element

A storage element is described in RealEstimate® by its capacity, the energy loss per unit of time and its efficiency. These properties make it easy to describe different types of storage (battery, electrolysis, compressed-air storage, etc.).

We examine the effects of different capacity of the storage. The comparison of the different storage types may be the topic of further investigation. In our example, storage elements of different capacities with an energy loss of 3%/day are examined. We have chosen this large energy loss rate to make the effect clearly visible. Most real storages have significantly lower loss rates. The storage element is assumed to be purchased at a price of €100/kWh. After the period of use, the residual value of the storage facility in the basic scenario including disposal costs is set at € 0.

26.2.5 Model Component Electrolysis

In this analysis, electrolysis is depicted analogously to the storage element. In model extensions, a more detailed description and an alternative use of the products (e.g., marketing/refining of the products) can be added.

26.2.6 Model Component Electricity Price

The market model describes the development of the electricity price broken down by its components. The individual components can be described deterministically or stochastically and linked to external drivers. In this example, constant values are used over the entire observation period.

This model component makes it possible to transfer a stochastic and seasonal flow of electricity into a stochastic and seasonal cash flow (if required, also taking into account foreign currencies). Regulatory influences depending on production and use are taken into account. In this way, self-consumption and feed-in are mapped. On the other hand, amounts of electricity that are supplied to the overall system from outside can also be mapped as stochastic cash flows.

26.2.7 Model Component Financing

Optimized financing can contribute to the success of a business model (e. g. Gees 2015). The selected ratio of equity and borrowed capital, as well as the different types of financing (loans, (silent) participations, participation certificates, partial loans, etc.) can influence the ratio of risk and return. Under certain circumstances, legal requirements may also have to be included here. In this analysis, different funding levels are examined.

26.2.8 Model Component Regional Economic Effects

The impact of local investments on a specific region may represent a key decision-making factor. To describe these effects, a model published by Fraunhofer IFAM (Nieters 2021) was simplified and implemented in the RealEstimate® framework that can be used for the Heide region and can also be adapted for other regions. The approach consists of assigning an impact on a specific region to simulated cash flows from investments and business models. The stochastic simulated cash flows can thus be used as a basis for determining the regional economic effects.

Direct, indirect and induced regional economic effects were taken into account as relevant variables for describing regional value added. These include, for example, different types of costs, tax components and types (including the distribution of regional components).

26.3 Storage Sizing Analysis

To demonstrate an analysis of a storage dimensioning with our generic model, we have chosen the example of a two-family house with a 10 kWp solar plant and different sized storages. The power generation is simulated over a period of 30 years on a daily basis in 5,000 stochastic scenarios. The variability of the weather/climate and the changing properties of the solar plant as well as the properties of the storage element are taken into account. The load profile is assumed to be constant over time at 7000 kWh/a. The electricity generated is primarily used to satisfy the load profile. Excess electrical power is drained into the storage element. If the storage is fully utilized, excess electricity is immediately sold at the corresponding market price. If the system does not generate enough electricity to cover the load profile, the stored energy is used first. If no stored energy is available, electricity is supplied immediately at the market price. The statutory levies are taken into account accordingly during generation, storage and withdrawal. The results essentially depend on the ratio between energy production, load profile and storage element. With constant conditions, the results can therefore be transferred to systems with different dimensions by scaling.

26.3.1 System without Storage Element

Figure 26.3 shows the seasonality in the expected value of the power generation of the solar plant and the power utilization. The degree of self-consumption of the electricity generated is shown in grey. The portion that could not be consumed and fed into the grid is shown in yellow. In order to cover the actual demand (load profile), additional electricity must be drawn from the grid, which is shown in orange. Due to the lack of a storage element, a comparatively large amount of electricity has to be purchased even in summer in order to ensure that the load profile is covered during the night. Since the load profile in the base scenario is assumed to be constant, the sum of self-consumption of self-generated electricity and additional grid purchases is also constant.).

Figure 26.4 (left) shows the cumulative amount of electricity generated by the solar plant, broken down into self-consumption and electricity fed into the grid. The cumulative amounts of self-consumption and fed-in together result in the annually generated amount of energy.

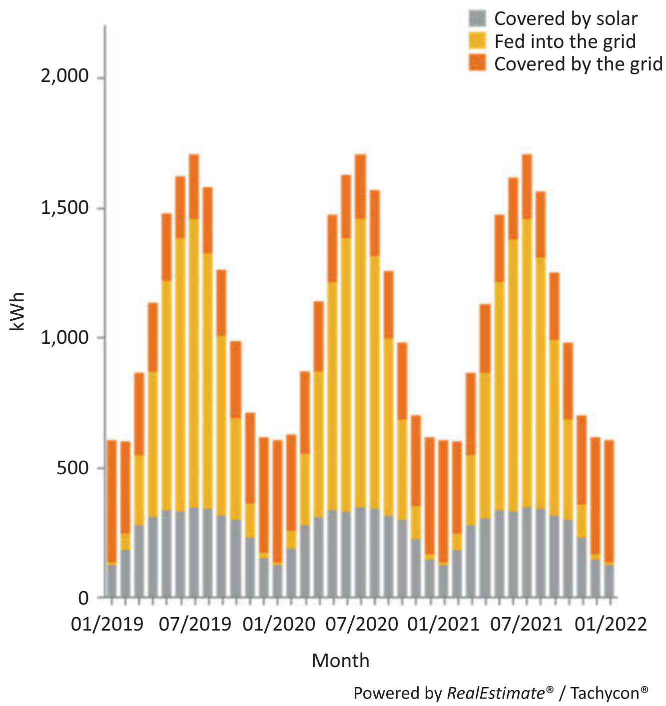

Figure 26.3: Expected electricity generation and utilization without using storage elements.

A feed-in tariff is received for the electricity fed into the grid. The electricity drawn from the grid must be paid for. Figure 26.4 (right) shows the expected energy purchase costs and the expected feed-in tariffs on a monthly basis. The operating costs of the system could also be shown. The price components of the electricity purchased (grid fee, etc.) could also be shown separately here.

26.3.2 System with Storage Elements of Different Dimensions

In order to optimize profitability, we examined the system with different storage capacities. We consider a system of power plant (operating expenses: 300 €/a), and storage (efficiency: 95%, daily storage loss: 3%) with storage capacities of 5 kWh, 10 kWh (approx. half daily requirement), 15 kWh and 100 kWh. Electricity price components are shown in Table 26.1. As expected, increasing the storage capacity from 5 kWh to 10 kWh or 15 kWh leads to a reduction in electricity purchases (see Figures 26.5–26.7). If the storage capacity is increased to 100 kWh (approx. 5 times the daily requirement), the feed-in quantity is reduced compared to a storage capacity of 10 kWh or 15 kWh without increasing the amount of self-consumption (see Figure 26.8).

This effect results from the energy loss of the storage facility, which is more noticeable with a larger storage facility due to the fact that filling the storage facility has priority over feeding it into the grid. Even the 10 kWh storage is not completely emptied overnight in summer. In this respect, a storage with larger dimensions cannot improve overnight buffering. In winter there is not enough excess energy available to fill a larger storage. For seasonal buffering (use of electricity generated in summer in winter), the loss rate of the storage (3%) is too high to make a significant contribution. Therefor there is no significant reduction of purchase need for a storage larger than 10 kWh. For very large storage losses increase without reducing the need to purchase from grid.

The smaller feed-in quantity resulting from this due to the limited demand and the loss amounts does not lead to a cost-efficient improvement in the security of supply. The variation in the height of the columns of the load profile is due to the different number of days in each month.

The electricity price model takes different components into account (Table 26.1). In our sample calculations, all listed components are taken into account. When transferring the model to other circumstances, electricity price components in the RealEstimate® software can easily be left out of the calculation if this is legally permissible in the given constellation (transferability).

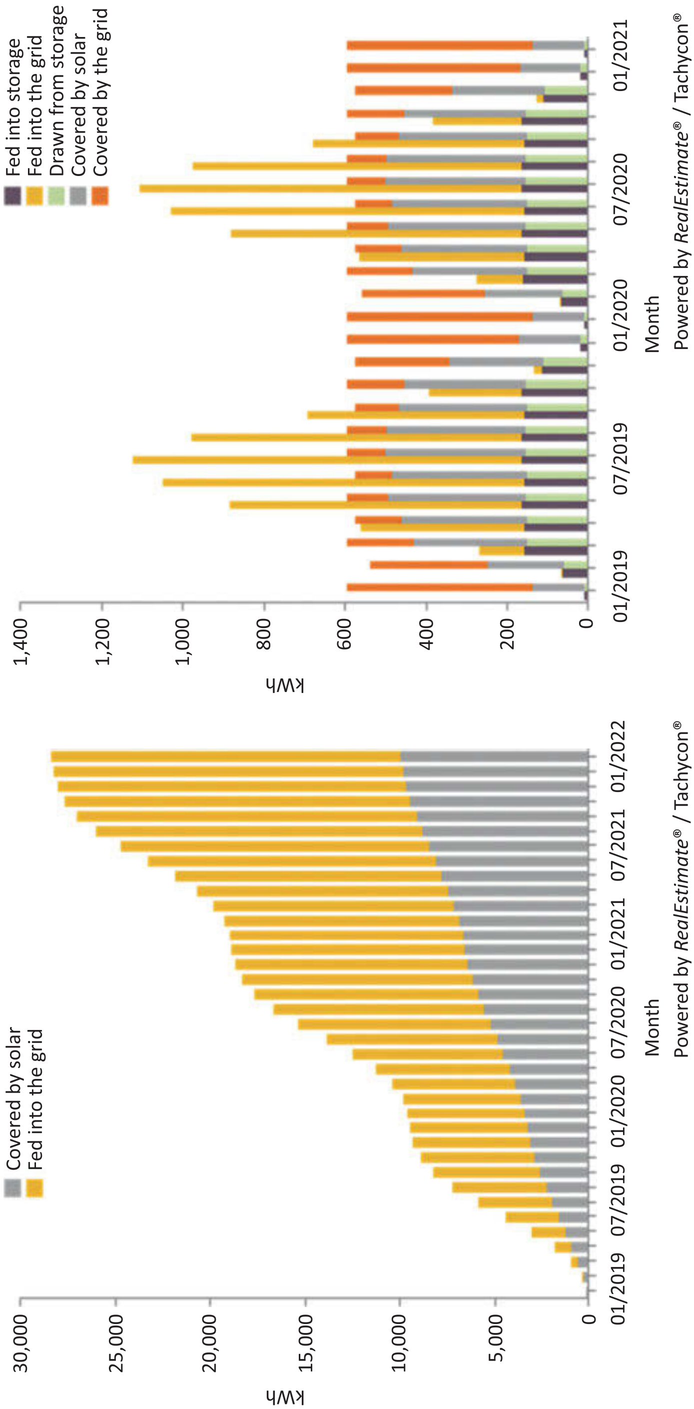

Figure 26.4: Cumulative amount of electricity generated (left) and cash flows for purchasing and selling electric energy (right).

Table 26.1: Electricity price components used in the simulation (Bundesnetzagentur 2019, Kost/Shammugam/Jülch et al. 2018, Schwenke/Bantle 2018, Wilms/Kalis/Meyer 2018).

Component	Amount	Unit
Prime cost	0,0620	€/kWh
EEG-surcharge	0,0679	€/kWh
Electricity tax	0,0205	€/kWh
Grid fee concession	0,0727	€/kWh
Concession fee	0,0166	€/kWh
CHO surcharge	0,0035	€/kWh
Offshore levy	0,0004	€/kWh
NEB 19 surcharge	0,0037	€/kWh
Switchable load allocarion	0,0001	€/kWh
Feed-in tariff	0,1147	€/kWh

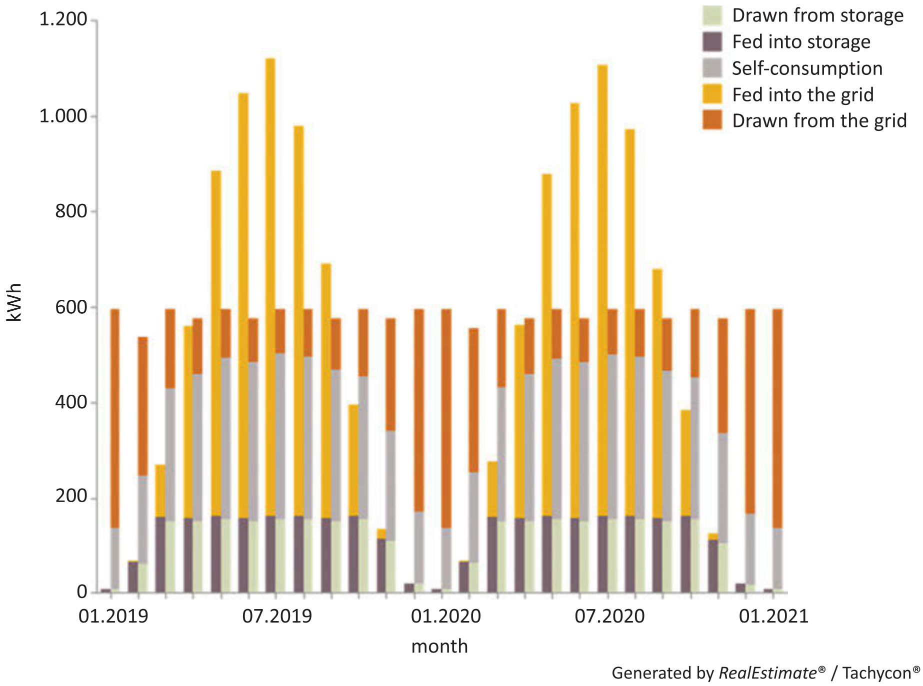

Figure 26.5: Expected flows of electricity in the system (storage capacity: 5 kWh).

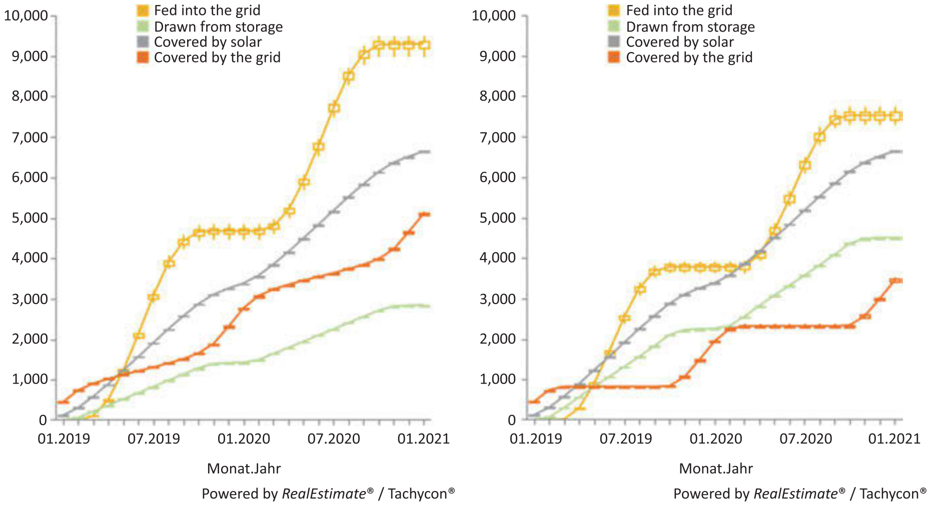

Figure 26.6: Cumulative stochastic flows of stochastic electricity flows in kWh (storage capacity: 5 kWh (left) and 10 kWh (right)).

26.4 Profitability Analysis using Properties of Rüsdorfer Kamp

In the RealEstimate® framework, analyses can be automatically created for all objects listed in the *Rüsdorfer Kamp* solar cadaster. This means that every resident of the Rüsdorfer Kamp can be provided with an indicative analysis.

The data used in the analysis (particularly property, consumption and market data) comes primarily from the Rüsdorfer Kamp solar cadaster. (Sauss 2019) The weather model (solar radiation) can be calibrated to regional weather data. No regional weather data was available for the present analysis, so an unvalidated estimate was made at this point.

Different scenarios are considered for the use of the electricity generated in excess of self-consumption:

1. The electricity generated is primarily used for self-consumption and then fed into the public grid with a feed-in tariff (0.0816 or 0.0793 EUR/kWh) as a second priority (variant 1). We analyse three different financing scenarios:
   a. The investment is made exclusively with equity
   b. The investment is 50% externally financed
   c. The investment is 100% externally financed
2. The electricity generated is primarily used for self-consumption and then made available for an electrolysis plant that is hypothetically to be built in Rüsdorfer Kamp. Different price scenarios are considered for the remuneration of the elec-

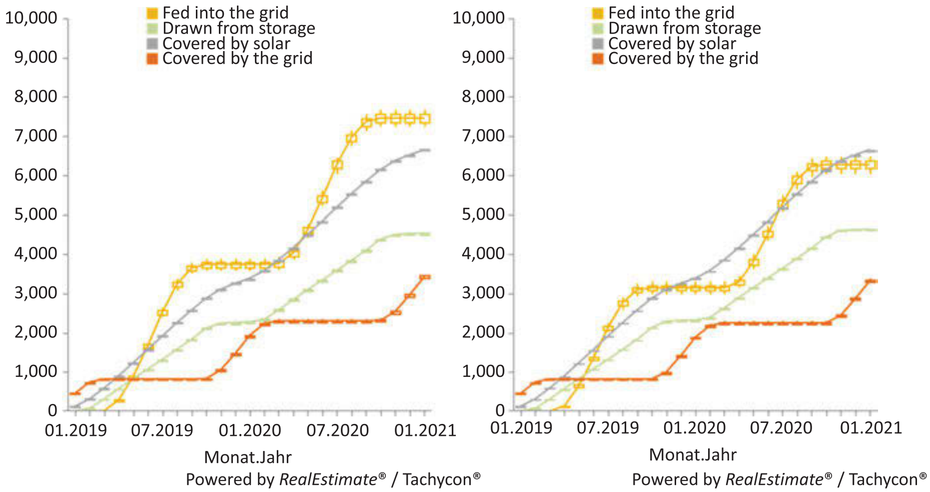

Figure 26.7: Cumulative stochastic flows of electricity in kWh (storage capacity: 15 kWh (left) and 100 kWh (right)).

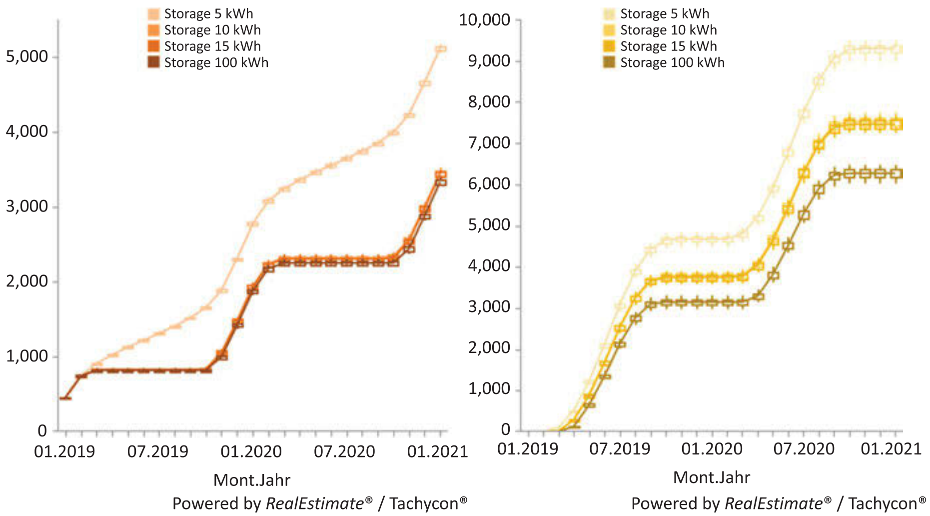

Figure 26.8: Left: Comparison of cumulated energy purchase from grid: No significant reduction of purchase need for a storage larger than 10 kWh. Right: Compare Feed into grid for storage capacity: for very large storage losses increase without reducing the need to purchase from grid. Ordinate given in kWh.

tricity to be supplied by the residents for the electrolysis, which are each 100% externally financed:

a. Feeding into a local electrolysis at 0.10 EUR/kWh. (Variant 2)
b. Feeding into a local electrolysis at 0.12 EUR/kWh. (Variant 3)

For our example analysis, we choose the geometry of a specific object of the Rüsdorfer Kamp (data see Table 26.2 and section “Model Component Solar Plant (PVA)”

26.4.1 Comparison of Different Funding Scenarios

Table 26.2 shows an overview of the technical data and simulation results of the simulated solar plant located on the roof of the example property. The solar plant will hypothetically be put into operation in April 2021.

Table 26.2: technical data and simulation results.

Dimension	**60 m^2**	**10,0 kWp**
Orientation	SO	
Roof pitch	50 °	
Annual yield	888 kWh/kWp	8.883 kWh
Material and construction costs	14.500 EUR	
Electricity consumption per year	3.807 kWh	990 EUR
	year 1	**year 2–5**
Self-consumption	1.505 kWh	7.579 kWh
Fed into the grid	6.371 kWh	27.376 kWh
Purchase from the grid	2.302 kWh	9.577 kWh
Degree of self-consumption	19,11%	21,68%
Degree of self–sufficiency	39,53%	44,18%

The degree of self-consumption is the proportion of the electricity generated by the power plant that is consumed in the building itself. This is shown in green in the Figure 26.9 (left). The rest of the generated energy is fed into the grid (variant 1). The degree of self-sufficiency indicates how much of the total electricity consumed can be covered by the solar plant. The rest of the electricity consumed has to be bought from the grid.

The higher the level of self-use, the lower the electricity bill, since the electricity price per kWh for end consumers is significantly higher than the remuneration per kWh for feeding into the electricity grid. The uncertainty in the simulated energy production results from the modelled fluctuations in the weather.

Figure 26.9 (right) shows the cumulative total costs of Variant 1 with its different external financing scenarios (0%, 50% and 100% external financing) compared with the cumulative costs receiving electricity 100% by the grid. The point in time at which the respective curve intersects with the curve of the grid reference indicates the respective break-even point. The time of break-even is influenced by individual factors (degree of self–consumption, roof pitch, orientation of the roof, dimensioning of the solar plant, degree of external financing, etc.).

The curves “Solar plant 50% debt” and “Solar plant 100% debt” bend down in 2041, since the respective loans have been repaid in full by this time and the burden of the annuity no longer applies.

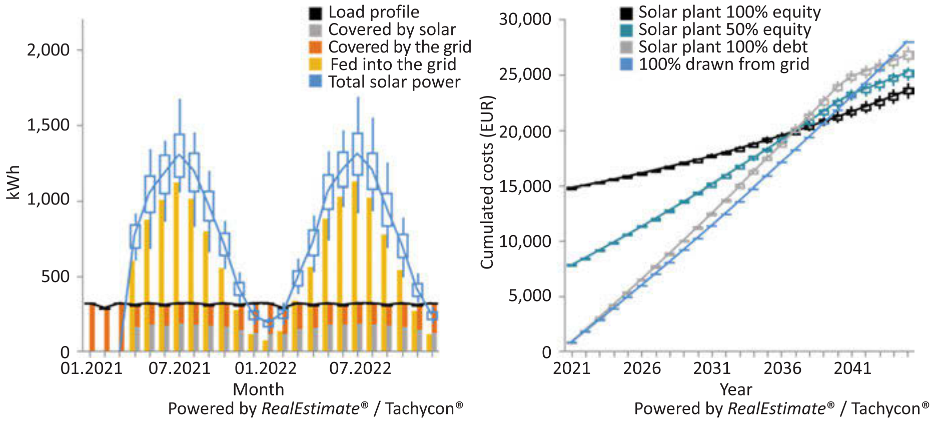

Figure 26.9: Left: Coverage of the load profile via solar energy (green) and electricity grid (red). Right: Cumulative costs of solar energy (funding level 0%, 50%, 100%) and cumulative electricity costs 100% drawn from the grid.

26.4.2 Comparison of Different Usage Scenarios

Figure 26.10 shows the cumulative total costs to the owner of the plant. The plant is financed completely from debt. Variant 1 (feeding into the public grid), Variant 2 (0.10 EUR/kWh remuneration for feeding into the electrolysis) and Variant 3 (0.12 EUR/kWh remuneration for feeding into the electrolysis) compared with the costs without using a solar plant, purchasing all electric energy from the grid.

The curves (apart from that of the 100% drawn from the grid) bend down in 2041, since the respective loans have been repaid in full by this time and the burden of the annuity no longer applies.

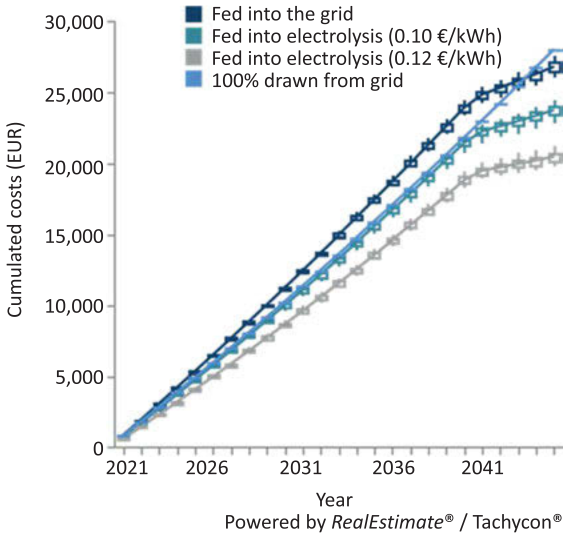

Figure 26.10: Cumulative total costs (100% funding) with excess energy being fed into the grid or feeding into a local electrolysis at 0.10 or 0.12 EUR/ kWh.

26.5 Regional Economic Effects

Investing in a specific region gains value added to the region. If the investor is located in the region, the revenues gained from the investment constitute additional value to the region. Direct additional value in form of the revenues itself, but also from the part of taxes, that flows back to the regional administration. If the object, that is invested in, is produced by regional producers, the producers also gain revenues in the region. These revenues are indirect value added, partly from materials from the region, partly by staff that is located in the region. If the revenues itself from direct and indirect value add is again spent in the region, this induces further value added. Direct value added can be estimated from the revenues and costs and the share of taxes, that comes back to the regional administration. To estimate indirect effects, we have to estimate the share of material and staff costs, that is achieved in the region. The induced value added can be estimated from a multiplier, that reflects the iterated regional reinvestment of gained revenues, that in each reinvestment step again gains some additional direct and indirect value added.

To analyse the impact of local investments on a specific region, direct, indirect and induced regional economic effects were taken into account as relevant variables for describing regional value added. These include, for example, different types of costs, tax components and types (including the distribution of regional components).

We use in this section the same example object for our analysis as in the section before including the data given in Table 26.3.

26.5.1 Direct Value Added

The generated returns are subject to different taxation depending on the individual tax rate. Figure 26.11 (left) shows the returns and the taxes incurred for a private person as operator (trade tax rate: 0%, individual income tax rate: 42%). Since shares of the different tax types (15% in this example) remain in the region, these shares contribute not only to the income after taxes, but also as direct regional value added. The components of the direct regional value added is shown in Figure 26.11 (right).

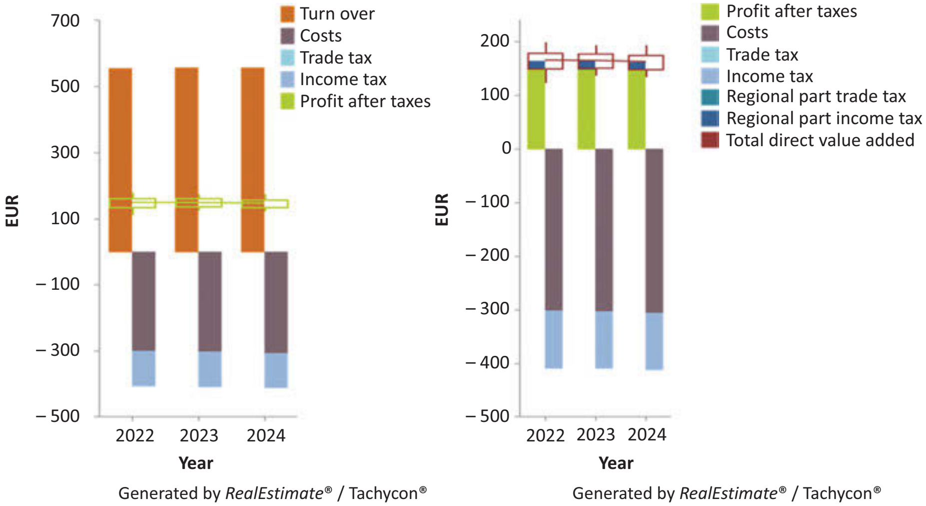

Figure 26.11: Revenues, costs, taxes and earnings after taxes (left). Income after taxes and direct regional value added depending on tax type (right). Tax rates and regional share of tax see Table 26.3.

Table 26.3: Simulation results.

Name	Cash flows in EUR	Tax rate	Regional share of tax
Revenues per year	557		
Costs per year	300		
Trade tax	0	0,00%	78,00%
Income tax	108	42,00%	15,00%
earnings after taxes	149		

26.5.2 Indirect Value Added

If the construction costs and operating costs are at least partly due to the services of regional service providers or the use of regional materials, there is an indirect regional added value in addition to the direct regional added value. In this example we assume a regional share of 20% (construction costs and operating costs). The operating costs contain personal costs and material costs in the ratio 2:1. Figure 26.12 shows the regional shares of the operating costs broken down by personnel and material costs.

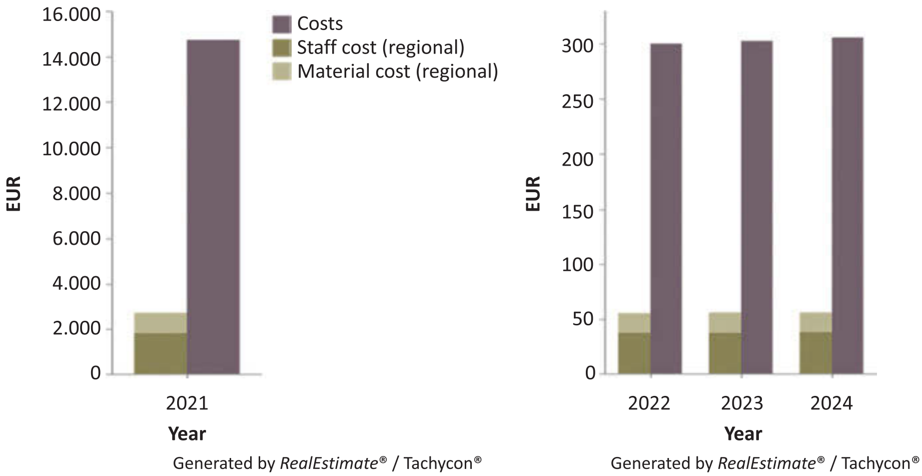

Figure 26.12: Regional shares of the costs in the first year (operating costs and, if applicable, building costs, left) and the ongoing operating costs (right).

26.5.3 Induced and Total Value Added

The earnings that are spent partly in the specific region induce a third type of regional value added, the induced value added. The multiplier for the induced value added is assumed as 22%. (BMVBS 2013) The total regional value added as the sum of direct, indirect and induced value added is shown in Figure 26.13 and Table 26.4. The value added in 2021 contains in particular the value added of the initial investment.

Table 26.4: simulated total regional value added. Values given in Euro.

Name	2021	2022	2021–2031
Direct value added	0	165	1,402
Indirect value added	1,258	26	1,498
Induced value added	277	42	638
Total value added	1,534	233	3,538

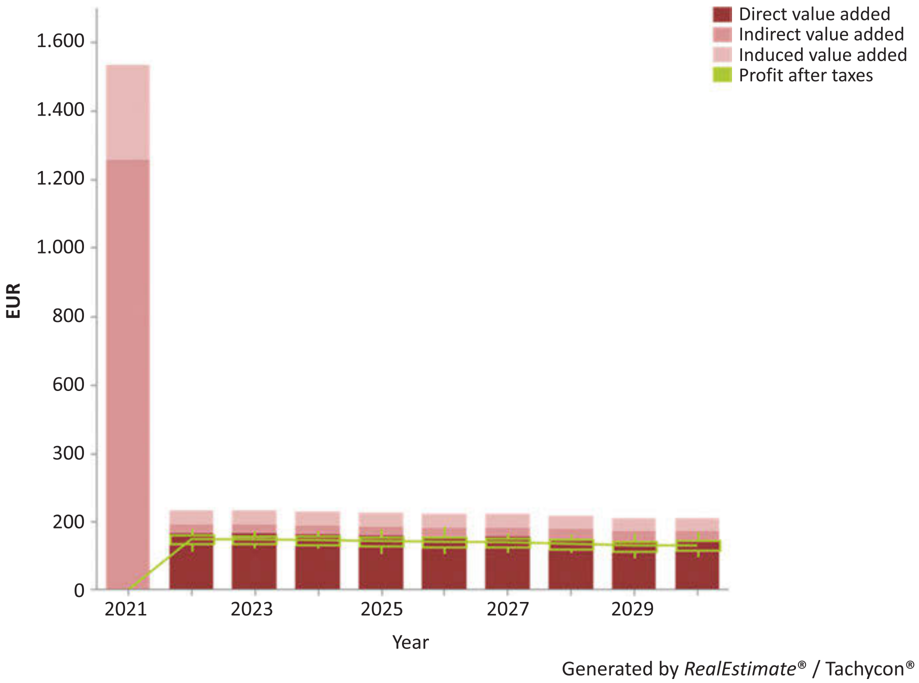

Figure 26.13: Total regional added value.

26.6 Conclusion

In this document we have presented a generic model for analysing the use of volatile solar power. Using application examples, it was shown how our generic model transports the interaction of different model components to the point of financing and regional economic effects.

The example of profitability analysis shows that an individual analysis should be carried out for each property in the Rüsdorfer Kamp. Factors such as the orientation of the roof, the dimensioning of the solar plants or the individual average electric power consumption of the respective household lead to individual results. For some buildings, some of the variants described may represent an economically viable alternative to purchasing electricity from the grid. This is particularly the case when the roof of the property is south-facing and self-consumption is relatively high. In contrast, for other objects, all three variants lead to additional costs compared to purchasing electricity from the grid. Here, self-consumption is typically relatively low, and the roof does not face south. So far, the present economic analysis has not taken into account the use of energy storage devices as described in Section 26.2. The use of energy storage systems can significantly increase the profitability of the solar system for the residents, as they may allow greater self-consumption of the electricity generated. In Section 26.2 we showed that even relatively small storage elements ("overnight" storage) can lead to a significantly higher self-consumption rate.

In the section "Regional Economic Effects", we show, that a positive economic effect can be generated not only for the individual operator but for the region. Such analyses can possibly provide decision-making aids for municipalities to support investments.

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Benedikt Meyer, Tino Mitzinger, Johannes Röder, Uwe Krien,
Heiko Waurisch, Reiner Schütt

27 Resilient Energy System Design of Low Emission Districts – A Model Chain from National Scenarios to Plant Operation

Summary: A central element in the energy transition is the transformation of existing districts towards low carbon energy system. Therefore, appropriate methods need to be developed for the design, dimensioning and assessment of district energy systems. This implies the development of modelling and data processing tools that can handle the increasing complexity not just of district energy systems but in general systems with high shares of decentralized and volatile renewable energy. This work shows an overall approach consisting of multiple modelling steps for the design of renewable and resilient district energy systems. This implies the generation of a consistent set of data regarding emission and cost time series of the German power sector for future scenarios, the design of the district energy system, as well as a way to assess the district energy system with respect to its resilience, and the development of operation strategies using software-in-the-loop.

27.1 Introduction

The goal of this paper is to show an approach of a model chain to ensure using consistent and comprehensible data answering different research questions using varied simulation tools. This approach has been developed within the research project QUARREE 100, which aims to establish a 100% renewable, resilient and system-supportive energy system in the existing residential area Rüsdorfer Kamp in the city of Heide located in the federal state Schleswig-Holstein of Germany.

Acknowledgements: This research was developed in the context of the research project "QUARREE 100 – Resiliente, integrierte und systemdienliche Energieversorgungssysteme im städtischen Bestandsquartier unter vollständiger Integration erneuerbarer Energien" (grant number: 03SBE113B, 03SBE113E) and funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the Federal Ministry of Education and Research (BMBF) of Germany.

Benedikt Meyer, Tino Mitzinger, Johannes Röder, Uwe Krien, Department Resilient Energy Systems, University of Bremen, Enrique-Schmidt-Str. 7, 28359 Bremen, Germany
Heiko Waurisch, Reiner Schütt, Westcoast University of Applied Sciences, Institute for the Transformation of the Energy System, Markt 18, 25746 Heide, Germany

https://doi.org/10.1515/9783110777567-027

Designing and simulating these local future-proof energy systems requires a vast amount of input data. Therefore, a model chain approach seemed to be a viable way of retrieving usable data and securing high transparency. To design system-supportive local energy systems data is needed which describes the interregional and national energy system like specific emission and cost time series as well as general data of components of the energy conversion technologies and local demand.

Besides dimensioning the components of the energy central of the district it is important to implement a control system to achieve the simulated results regarding emissions and cost estimated in the designing phase. Therefore, a Modelica model has been developed with interconnections to Matlab/Simulink and TwinCAT as well as Python scripts to test different operation modes and conditions with a digital twin.

The article is structured as follows. Beginning with short section about existing scientific work (27.2 Existing Scientific Work and Modelling Approaches) showing different approaches to design district energy systems, the approach of this work with its different parts of the before mentioned model chain is described in chapter 27.3 Methods. After that follows the presentation of the results in Section 27.4 results, and finally a discussion and conclusion of the introduced approach (chapter 27.5 Discussion, Conclusion and Outlook).

27.2 Existing Scientific Work and Modelling Approaches

Since each district – especially existing rural districts – is different in terms of social structures and building stock as well as with respect to the mixture of residential and commercial buildings it is obvious that the energy demand varies both in terms of timing and quantity. Therefore, and since the scope of each project or research group is different, a variety of modelling approaches have been developed. In literature are a few existing detailed review articles regarding tools and methods for designing and optimising district energy systems. (Reynolds/Ahmad/Rezgui 2018, Allegrini/Orehounig/Mavromatidis et al. 2015, Keirstead/Jennings/Sivakumar 2012, Hiremath/Shikha/Ravindranath 2007, Connolly/Lund/Mathiesen et al. 2010, Schweiger/Heimrath/Falay et al. 2018, Sola/Corchero/Salom et al. 2020) Mostly they give an overview over methods used to deal with specific aspects like sizing district heating networks or solar energy potentials. Nevertheless, integrated holistic approaches to design district energy systems are becoming more.

(Allegrini/Orehounig/Mavromatidis et al. 2015) have shown that there is a need for interlinking tools that enables interested parties both to design and dimensioning as well as to integrate operation and control strategies in models for energy system components, buildings and network links. They further state that different tools are needed ranging from simple to detailed approaches and different granularity to address planning, design and operation issues. (Bollinger/Davis/Evins et al. 2018) are also campaigning for multi-model ecologies since energy systems became more complex and models need to address multiple scales, disciplines and perspectives. Such multi-model ecologies or multi-domain urban-scale energy modelling tools (Sola/Corchero/Salom et al. 2020) are built based on a sequential (pre-processing), co-simulation or integrated approach. The review from (Sola/Corchero/Salom et al. 2020) seems to be the most recent regarding district energy systems modelling and contains an overview of recent tools.

For example, the *OpenIDEAS* (open framework for integrated district energy simulation) (Baetens/De Coninck/Jorissen et al. 2015) approach focusses on simulating the energy demand of residential buildings and neighbourhoods using several Modelica and Python modules. They developed two Modelica libraries. The first one is *IDEAS* (Integrated District Energy Assessment by Simulation) to simulate the thermal, electrical and control at building and district level. To calculate boundary conditions for the Modelica models, they developed an additional package: *StROBe* (Stochastic Residential Occupancy Behaviour). It is used to get time series for occupancy, receptacle load, internal heat gains, space heating, set point temperatures and hot water redraws at a 1-minute time resolution for residential cases. The second Modelica library is *FastBuildings*. A low-order building model compatible with *IDEAS* and supplemented with another Python package *GreyBox* to obtain grey-box models as a control model.

Another example is an older approach the *HUES* platform (Bollinger/Evins 2015) which comprises a tool set to support design and operation of district energy systems. It mainly consists of three parts: 1. dynamic thermal simulation of buildings to derive the energy demand in an hourly resolution, 2. the energy system which represents the energy central and supplies the needed energy via storage and conversion and 3. an optimization algorithm.

In addition there are a few more tools, frameworks or models mentioned in literature and used by researches like *oemof* (open energy modelling framework) (Hilpert/Kaldemeyer/Krien et al. 2018) and *OSeMOSYS* (Howells/Rogner/Strachan et al. 2011). Both have been extensively compared within a Master Thesis which concludes that the basic structures and simulation results using the same boundary conditions and input data are comparable while *oemof* has more efficient mathematical structures. (Muschner 2020) *Oemof* provides a toolbox in form of different packages to comprehensively design and analyse cross sectoral energy systems. Important packages of *oemof* regarding district energy systems are *oemof.solph* (Krien/Schönfeldt/Launer et al. 2020) and *oemof.dhnx* (Röder/Meyer/Krien et al. 2021). *Oemof.solph* basically allows in this case for an cost optimal design of an energy central while *oemof.dhnx* is a package to design cost optimal district heating systems.

Most of the tools and modelling approaches regarding district energy systems are focussing on specific aspects of it, are not open source or are not as easily accessible to the authors of this article. Since especially *oemof* emphasizes open science and collaborative cross-institutional software development, it was chosen as a starting point for the main aspects of this work. Similar to the multi-model ecology approach, we use additional tools like Modelica or Simulink for specific tasks.

The digital twin is also of great importance in the area of plant visualisation and operation which is why in the process industry, the usage of digital twins has become the central tool for system development, process optimisation and plant testing. (Dietrich 2017) It simplifies planning, initial operation, training and maintenance there. The Procedures, software tools, further tools and special challenges for creation and usage have been introduced and used for years and can be used as a basis for transfer to energy systems in residential districts. (Schüller/Modersohn/Kawohl et al. 2019) In the case of resilient energy system design digital twins could be used for assessing the designed energy systems.

27.3 Methods

For the development of resilient district energy systems, that are characterized by low emissions and a future-proof design for the upcoming decades, the modelling approach with subsequent modelling steps as illustrated in Figure 27.1 is pursued.

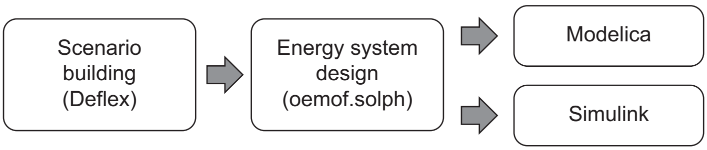

Figure 27.1: Overview of modelling approach.

The first step is the scenario building. Therefore, an energy system model for the national energy system is developed with the software *Deflex* (Krien 2019) with scenarios up to the year 2050. The next step is the design of the energy supply and infrastructures on district level dependent on the different scenarios of the upstream energy system. Then, the resulting design of the local energy supply is further analysed with detailed physical simulations based on Modelica and Simulink models to evaluate the district energy system with respect to its resilience and system behaviour. The following sections provide a more detailed insight in the single modelling.

27.3.1 Scenario Building with Deflex

Deflex (Krien 2019) is a cross-sectoral and multi-regional model with a focus on a national or supranational level. It is explicitly designed to create key values to evaluate

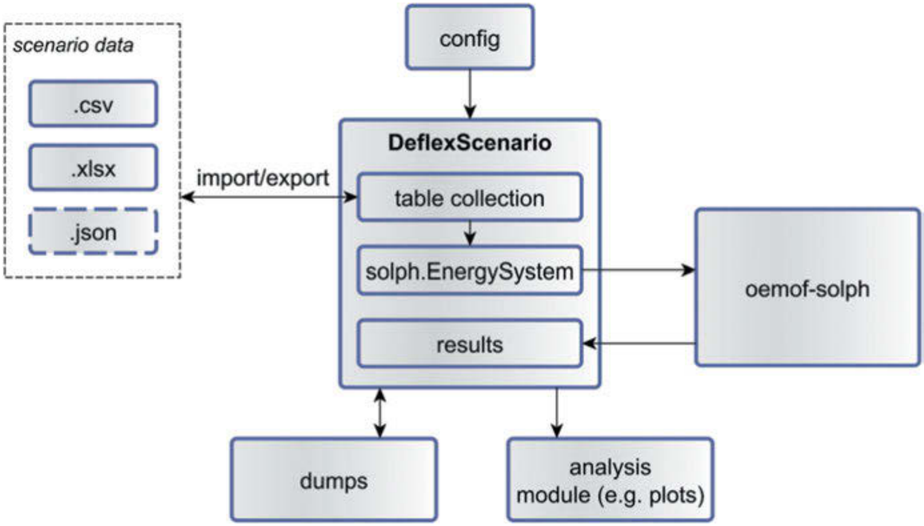

Figure 27.2: Structure of the Deflex package (Krien/Röder 2022).

detailed local models. The presented model chain is used to produce emission and cost time series of the German energy market for various scenarios.

Figure 27.2 shows the structure of *Deflex*. A *Deflex* scenario is defined by a set of tables represented by spreadsheet folder with different sheets or a directory of csv files. In these tables, one or more regions can be defined and connected with transmission lines. At the current state of *Deflex* only electricity transport can be modelled while the natural gas or hydrogen structure is assumed to be unrestricted. The obligate base of each region is the definition of the power sector with its electricity demand, power plants, commodity sources, transmission lines and storages. Optionally, additional sectors like, heat, gas and mobility can be added.

The model formulation is based on *oemof.solph* (Krien/Schönfeldt/Launer et al. 2020) which makes *Deflex* stable and expandable. *Deflex* has integrated functions to extract typical key values and time series like costs and emissions of the electricity sector. Using these time series can improve the evaluation of the electricity import and export of local energy systems, such as districts or buildings, but the results must be interpreted carefully especially for future scenarios.

It is difficult to define the power plants for future scenarios with regard to the spatial distribution and size of the units. Taking all uncertainties into account future scenarios are kept simple, which leads to uncertainties and little differentiated time series especially for long-term scenarios. Furthermore, the costs are determined by the marginal costs of the power production that will converge to zero for an energy sector based on renewable energies.

Nevertheless, *Deflex* is a useful tool to model the surrounding of a coupled local energy system, which works fine in the presented way for present and near future scenarios. For long-term scenarios, new key values have to be developed to evaluate local systems and to design system-supportive local energy systems.

27.3.2 Design of District Energy System

The development of the energy supply concepts and infrastructures on district level in turn follows also a multi-step approach for the single parts of the energy system. Figure 27.3 gives an overview.

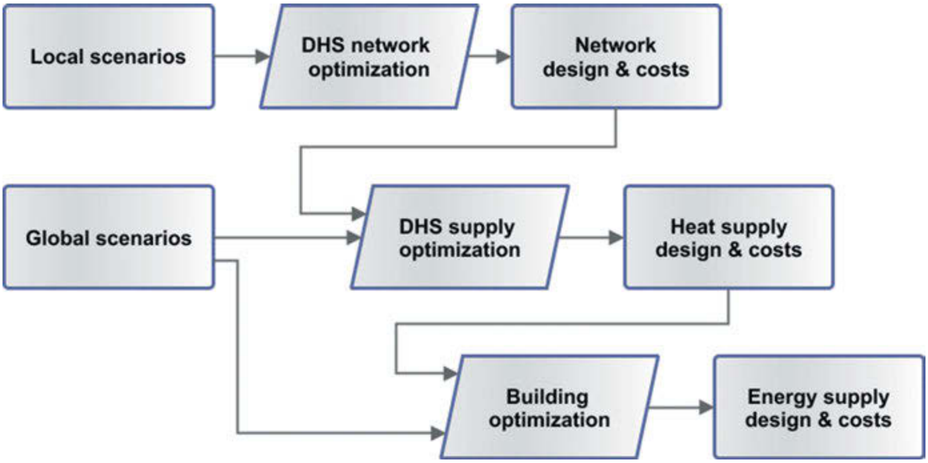

Figure 27.3: Modelling steps for the design of district energy systems.

The first step is the design of the district heating network dependent on different demand scenarios for the existing building stock (Local scenarios), that are characterized by different connection and refurbishment scenarios. For this purpose, the new open source library *DHNx* is developed that provides a flexible optimization approach to determine the topology and the sizing of the pipeline network for a fast estimation of the costs for the district heating network for different scenarios. (Röder/Meyer/Krien et al. 2021) The resulting costs and thermal losses for the potential district heating systems are required as input for the optimisation of the heat supply site.

The next step is the design of the district heat supply site dependent on the future scenarios of the upstream energy system, that are called global scenarios as they are independent of the contemplated district. The global scenarios consider different shares of renewable energies in the upstream energy infrastructures of power grid and gas network until the year 2050, and result from the scenario building with *Deflex*. Therefore, the dynamic (time-resolved) emission factor is used as grid based reference quantity for exchange of electricity with the upstream power grid. The usage of a dynamic emission factor affects the design and operation of district energy systems, and aims to obtain a system-supportive design (see also Röder/Beier/Meyer et al. 2020). The modelling approach for the heat supply site is carried out with an *oemof.solph* (Krien/Schirmeister/Schönfeldt et al. 2021) investment and unit commitment model for the energy converter and storage units. With this model, the trade-offs between an emission optimal and a cost-optimal system design are analysed via a Pareto-optimisation for each of the global scenarios. The modelling background and optimization approach for designing the district heat supply is given in (Röder/Beier/Meyer et al. 2020).

In the last modelling step, the energy supply on building level is optimized for two cases: the heat supply via district heating system (DHS) based on the results of the previous modelling step is compared with an individual heat generation. For this purpose, an *oemof.solph* investment and unit commitment model for the energy converter and storage units on building level is deployed. In context of the increasing sector coupling, the entire energy system of the buildings, including the electricity supply, is optimized with respect to costs and emissions. The calculation is performed for the global scenarios of the upstream energy system and the local scenarios that respect different potential refurbishment developments of the building stock as well as different connection quotas. By the variation of the connection quota different heat demand densities are simulated, which makes the comparison of the results to existing recommendations of heat demand densities for the feasibility of DHS possible. The time-resolved characteristics of the volatility of the renewable power generation of the electricity grid is considered in the same way as for the design of the district heat supply site by an assessment of the emissions of electricity import and export based on a dynamic emission factor. The comparison of the heat supply via DHS and individual heat supply aims to answer the question to what extent the different development path for the upstream energy system influence the feasibility of a DHS compared to an individual heat supply from a cost-optimal system to reaching carbon-neutrality. The purpose of the approach of Figure 27.3 is to answer and to identify the scenarios in which district heating systems are future-proof infrastructure decisions.

27.3.3 Methodology for Resilience Assessment of Urban District Energy Systems

Due to the digitization, defossilization and decentralization of the energy supply, the complexity of the energy system is increasing. One way to address the vulnerability that goes along with this complexity is through a resilient system design. Resilience describes the ability of a system to maintain its performance even under stress and turbulent conditions. (von Gleich/Gößling-Reisemann/Lutz-Kunisch et al. 2010) The design concept "Resilient energy systems" can be specified by resilience-enhancing structures and functionalities, so-called design principles. These design principles are derived from empirical values from evolutionarily proven ecosystems (von Gleich/ Giese 2019) as well as from precautionary risk management (Brand/Giese/von Gleich et al. 2017).

As part of the QUARREE 100 research project, the resilience of heat supply concepts for an urban district in the German city of Heide was examined. For this purpose, the resilience-enhancing structures and functionalities redundancy, diversity, loose couplings as well as buffer and storage capacity were evaluated using operationalised indicators to enable a comparison of the resilience of different heat supply scenarios. The methodology used to operationalise the evaluation indicators is briefly explained below. More detailed information on the used methodology can be found in (Mitzinger/Röder/Their 2020) and (Röder/Mitzinger/Their et al. 2020).

Redundancy

Redundancy means the duplication or multiple presence of similar system components. If one component fails, operation will not be affected since another component can effectively substitute the missing capacity. The installed capacity of the system should therefore be oversized in relation to the maximum power requirement of the system. Furthermore, a homogeneous distribution of the installed capacity over a large number of supply units enhances the redundancy of the system.

Hence, the indicator for the redundancy assessment equally considers the oversizing of the installed capacity as well as its distribution and the number of supply units.

Diversity

According to (Stirling 2007), the diversity of a system is described by three elements: variety (number of option categories in the system), balance (distribution of the system elements across the option categories) and disparity (difference between the option categories).

For the assessment of the diversity the Stirling index was selected, since it takes all three elements into account. A more detailed explanation of the Stirling index can be found in (Stirling 2010) as well as a detailed application example of the methodology in (Mitzinger/Röder/Their 2020, Röder/Mitzinger/Their et al. 2020).

Loose Couplings

The design principle “loose coupling” distinguishes between couplings, which are able to separate (loose couplings) and those that cannot separate (rigid coupling). (Gößling-

Reisemann/Thier 2019) One advantage of loose couplings is that cascading continuations of failures can be prevented in the event of a disruption.

The assessment of whether couplings are loose or rigid is carried out by analysing the dependencies of supply technologies to their associated infrastructures. As an example, line-bound energy carriers are to be regarded as more rigid than solids, since solids can be distributed and stored in a variety of ways. The assessment indicator for the grade of lose couplings in a system is the ratio of the thermal energy provided by loosely coupled system units to the total annual thermal energy supply.

Buffer and Storage Capacity

The design principle of buffers and storage takes into account the capacity of the system to compensate for small fluctuations in the system performance up to short-term failures of system elements. The assessment indicator for the buffer and storage capacity is the period the system can maintain a safe system performance under maximum performance requirements only due to its buffer and storage capacity.

27.3.4 Matlab/Simulink and TwinCAT for Plant Testing, Operation and Visualisation

In addition to the system behaviour, the resilience of energy systems is significantly affected by the operating and control concept as well as by the operating behaviour of the individual plants in the different operating states. It is analysed how the plants behave when controlled locally via a control panel and when controlled remotely via a control system. The operating modes to be considered are automatic mode as well as manual mode and here in particular setup mode. It has to be clarified how the start-up and shut-down behaviour of the plant works, how the plant behaves during the initial start-up, during the restart after a main failure, in the event of a fault and after the elimination and acknowledgement of a fault that may occur in the plant itself or also in the communication technology. TwinCAT is used to simulate precisely these scenarios and make them observable. To connect the energy system, the model in QUARREE100 is complemented by the associated control panel and display unit of the plants and the associated interfaces. Only in this way, it is possible to analyse the reaction to automated and manual control interventions as well as faults at plant level in the system network.

Figure 27.4 shows the model structures for the resilience studies with the model of the energy system at plant level with Modelica, the modelling at feedback control level with MATLAB/Simulink, the control simulation with TwinCAT and the connection of the control panel and display.

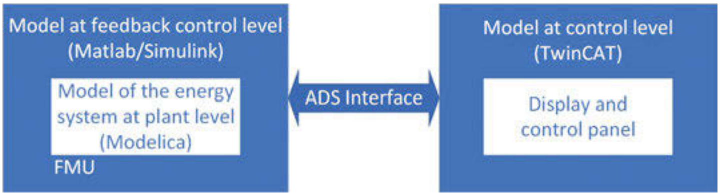

Figure 27.4: Model chain from the physical plant model to control panel and display.

The simulation results from the object-oriented modelling of plants are transferred to the platform for programming, numerical calculation and design at the feedback control level, which is then used to exchange data with the automation software for control technology running on a PC (soft PLC) and to integrate the control panel and display. With the help of the soft PLC, it is possible to switch on and off the plants, specify set points, simulate and acknowledge errors and visualise the data.

For this purpose, a functional mock-up unit (FMU) is generated for the physical model of the plants via the so-called functional mock-up interface (FMI). The FMI is a free standard used in industry that defines a container and an interface to exchange dynamic models using a combination of binaries, C code and XML files zipped into a single file. (Modelica Association 2022) The FMU is imported into Simulink and the Modelica model is used within the Simulink environment. Simulation results are compared and possible error messages and faulty behaviour are analysed in more detail.

The calculated output values are then further used in the TwinCAT software. With the import of the FMU, all inputs and outputs in the model are automatically generated and made accessible via the Simulink user interface. Input parameters are defined, initial values are specified and load profiles are read. Output parameters are processed further in order to calculate additional parameters or to convert data types. This processing of input and output parameters takes place in Simulink and is necessary for the simulation and visualisation. The modified output parameters are further used in TwinCAT.

A separate software module, the Beckhoff TE1410 Interface for Matlab/Simulink, enables an Automation Device Specification (ADS) interface to be established between Simulink and the TwinCAT visualisation software. ADS describes a device- and field-bus-independent interface governing the type of access and communication to ADS devices. (Beckhoff Automation GmbH & Co. KG 2022) In the Simulink and TwinCAT modules, the mutual mapping of variables is done by defining the indices that are used. The output parameters of the FMU block are written to a global variable list created in TwinCAT. This allows the exchange of data and signals bidirectionally. ADS communication takes place via a port created in TwinCAT. For this purpose, the global variable list is created in advance in order to write the values into the matching variables. Variables are also created that are written from the PLC to the Simulink model. The values of the variables are then used for the visualisation.

An interactive control panel and display interface (HMI) is created using TwinCAT HMI. This HMI is used to navigate to various areas. The interface is structured into the overview, the individual plants, the piping and instrumentation diagram (P&ID) and the changeable simulation parameters. In addition to the overview for selecting the plants, the electric grid and the heat grid, the gas boiler, the heat pump, the high-temperature heat pump, the combined heat and power (CHP) and the electrolyses used in QUARREE100 are offered for selection under facilities.

Figure 27.5 shows the visualisation, the measuring points and the control panel elements of the CHP according to the P&ID. On the left side is the CHP plant itself, on the right side the connection to the heat grid. Flow and return flow temperatures, mass flows and operating states of the CHP are displayed at the correct spots. In addition, the tag number of the respective measuring point can be displayed. The tag numbers are then defined in more detail in the legend that can be shown and hidden. Each plant has its own visualisation and there are also overview images available. The operation and visualisation is designed for a touch-screen panel.

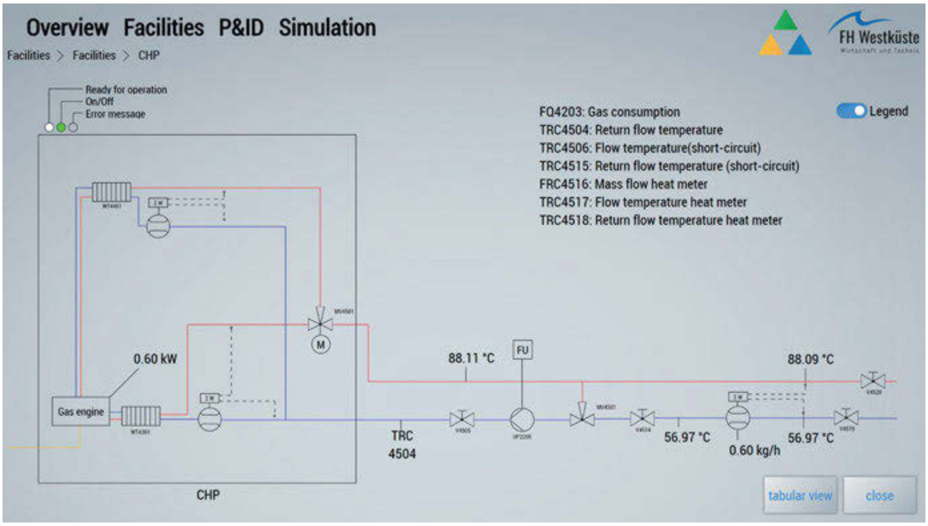

Figure 27.5: Visualisation of the CHP plant with connection to the heat grid.

Additional functions are being implemented for the resilience studies. These include displaying the time curves of flow and return flow temperatures and acknowledging, displaying and saving error messages. The PLC is also used to programme the control and feedback control in case of a malfunction. In this way, faulty behaviour of the system is detected in advance. Possible conflicts and improvements for initial operation and for ongoing operation are identified.

27.4 Results

In the following section a selection of the results of the individual simulation steps due to the limited space is shown. Beginning with the results of the scenario building and the district heat supply site, results of the resilience and system behaviour analyses are presented. Further results or details can be found in the publications cited accordingly, insofar as references can be made due to temporal overlaps in the publication processes.

27.4.1 Scenario Building with Deflex

Started with a base scenario of 2014 three further scenarios for 2018, 2030 and 2050 based on the technical report "Klimaneutrales Deutschland" from Agora. (Prognos/Öko-Institut/Wuppertal-Institut 2020)

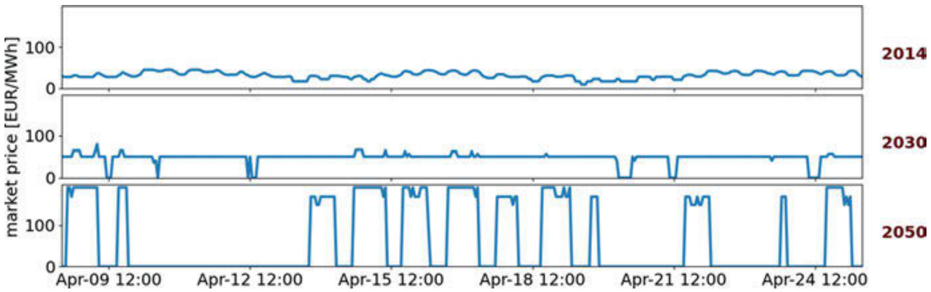

Figure 27.6: Calculated market price for three different scenarios (2014, 2030 and 2050) in *Deflex.*

Figure 27.6 shows the calculated market price for scenarios of three different years. In the scenario of 2014 power plants are grouped by efficiency and fuel so that about 90 blocks of power plants are modelled. Therefore, the market price of 2014 shows various price levels. Due to uncertainties and limited data in the Agora report the future scenarios of 2030 and 2050 contain only one power plant block for each fuel, so that only a few price levels exist. The difference of price levels increases over the years which will make the scenario more sensitive to the assumptions for future scenarios. The marginal costs of the 2050 scenario is dominated by the assumed price for hydrogen import, and the commitment of the hydrogen power plants depends on the usage of the different storages and the availability of wind and solar radiation which is hardly predictable for 2050. However, under the assumption that the weather patterns behave similarly as in the deployed weather year, the results reflect times of high and low energy prices, which can be used for designing a flexible local energy system.

In parallel to the cost time series, emission time series have been processed. These time series have been used for example to calculate the time when a CHP plant with natural gas will decrease or increase the average CO_2 emission and have been used in the next step designing the district energy system. In the transition of the power sector this could be an option for local systems to gain an emission bonus, but towards an emission-free power sector this possibility will be obsolete.

27.4.2 Design of District Energy System

The results of the optimization of the heat supply site shows that heat-pump capacities in combination with a thermal storage is of great importance for a future carbon-neutral heat supply in all scenarios. A combined heat and power unit helps to reduce emissions in short term. However, only if the gas network has a high share of renewable energies, this technology will compete with electricity based heating via heat-pumps. The results show that electrolysis is at least in short term not a viable option for designing a cost-efficient carbon-neutral district heat supply. (Röder/Zondervan 2022)

The comparison of district heating systems (DHS) and individual buildings-wise heat generation reveals that DHS become economically feasible already at lower heat demand densities, if the overall emissions of energy supply are reduced towards a carbon-neutral energy system. A district heat supply can react more flexibly on the availability of renewable electricity in the upstream power grid compared to individual heat generation. The impact of the scenarios for the upstream gas network considering a low and a high share of renewable synthetic gas on the heat density threshold is low. Even if the share of renewable synthetic gas in the gas network is very high, and despite the existing gas infrastructure, the trend is going to the opposite direction towards favouring DHS. In case of a high share of synthetic renewable gas, the gas can be more efficiently used in the DHS supply site by coupling combined heat and power units with heat-pumps and large scale thermal storage.

In contrast to the scenarios for the upstream infrastructures, the local scenarios (see Figure 27.3), that consider different levels of energetic refurbishment and different building types, have a stronger influence on the heat density threshold, and especially the individual buildings point of view differs clearly. This means that individual factors, such as usable roof area for PV, electricity demand, e-mobility, geothermal or other heat potentials, and also space for the installation of thermal storage capacities become more important in a future strongly sector-coupled energy system for the feasibility of DHS.

The analysis of the refurbishment scenarios considering different temperature levels and a reduction of the space heating demand clearly shows the benefits of refurbishment to obtain carbon-neutrality. With respect to the heat density threshold, a clear shift towards lower heat densities is not observed with increasing refurbishment measures and lower supply temperatures for achieving carbon-neutrality. This stands in contrast to literature sources that state that low temperature district heating systems are feasible at lower heat densities.

27.4.3 Resilience Assessment

As part of the research project, various concepts for the energy supply in the district were developed and one of them specified in detailed expansion stages. The 15 resulting scenarios were examined in the resilience assessment: the status quo, heat concepts 1 to 8 as well as three expansion stages with two different variants of the finalized energy concept (see Table 27.1). Figure 27.7 shows the installed thermal capacity of the individual heat supply units and the thermal load of the district in the respective heat supply scenarios.

The status quo consists of gas and oil boilers that supply the specific household. The supply concepts and the finalized energy system with its variants and expansion stages are district solutions in combination with a heating network. These variants with the installed plants are displayed in Figure 27.7. A thermal energy storage, up to three heat pumps, combined heat and power plants, gas boilers and waste heat from the electrolyses are used to cover the heat load. The scenarios differ in the number of plants, the installed capacity and the operation of the various units. The spectrum ranges from a high proportion of renewable energy sources (Concept 1 and 2) to an increased use of fossil or synthetic fuels (Concept 8). The finalized energy concept with its three expansion stages forms a middle path, which, in addition to the high proportion of renewable energies, also provides for a high installed capacity of conventional combustion technologies in order to offer a sufficient back-up.

Figure 27.8 shows the results of the resilience assessment of the district in the respective heat supply scenarios. The assessment of the different resilience indicators shows that concept 1 and 2, due to their high and diversified installed thermal capacity of supply units and heat storage, can achieve the highest scoring of all supply concepts in all four indicators.

In the finalized energy concept, all indicators decrease with the increasing expansion stages of the heat supply. This is due to the almost constant supply units and storage portfolio. In the initial stage, the installed thermal supply and storage capacity of the system is oversized for the low initial load in the district. This has a positive effect on the resilience of the system. However, this effect is equalized with increasing load in the later expansion stages.

Since no information on the storage capacity is available in the reference scenario status quo, this indicator could not be applied. Due to its small-scale, distributed system structure, the reference scenario has a high redundancy index. However, this is only given if the failure of a supply unit is related to its impact on the entire district. The affected household has no redundancy and would therefore remain completely

Table 27.1: Description of the examined scenarios.

Scenario	Description
Status quo	current state; 2.5 MW thermal district load; conventional gas and oil boilers; domestic supply
Concept 1	Concept MaxFlexLowEx; 2.5 MW thermal district load; large installed thermal capacity of heat pumps and gas boilers for maximum of flexibility; low emissions
Concept 2	Concept MaxFlexLowEx+; 2.5 MW thermal district load, large installed thermal capacity of heat pumps and gas boilers for maximum of flexibility; low emissions; small electrolysis
Concept 3	Concept: small electrolysis; 2.5 MW thermal district load; small electrical powered supply units; no chp
Concept 4	Concept: system beneficial; 2.5 MW thermal district load; large electrolyser; small heat pump; high amount of full load hours of electrical powered supply units
Concept 5	Concept: large electrolysis; 2.5 MW thermal district load; large electrolyser; small heat pump; regular amount of full load hours of electrical powered supply units
Concept 6	Concept: economical. optimized; 2.5 MW thermal district load; large electrolyser; small heat pump; high amount of full load hours of chp
Concept 7	Concept: no EEG; 2.5 MW thermal district load; large electrolyser small heat pump; regular amount of full load hours of chp
Concept 8	Concept: extend perimeter; 3 MW thermal district load; like concept 7 with a higher thermal load due to an extended perimeter of the heat supply area
Stage 1 – V1	expansion stage 1; 1.6 MW thermal district load; 459 kW_p photovoltaic
Stage 1 – V2	expansion stage 1; 1.6 MW thermal district load; 275 kW_p photovoltaic; 50% direct use of the chp provided electricity
Stage 2 – V1	expansion stage 2; 3.2 MW thermal district load; 1161 kW_p photovoltaic
Stage 2 – V2	expansion stage 2; 3.2 MW thermal district load; 696 kW_p photovoltaic; 50% direct use of the chp provided electricity
Stage 3 – V1	expansion stage 3; 4 MW thermal district load; 1442 kW_p photovoltaic
Stage 3 – V2	expansion stage 3; 4 MW thermal district load; 865 kW_p photovoltaic; 50% direct use of the chp provided electricity

without heat supply. The low diversity in the reference scenario is caused by the homogeneous installed capacity of conventional boilers. Due to the high proportion of oil-fired boilers, which are relatively loosely coupled to the upstream infrastructure, the reference scenario has a high value for the lose couplings indicator.

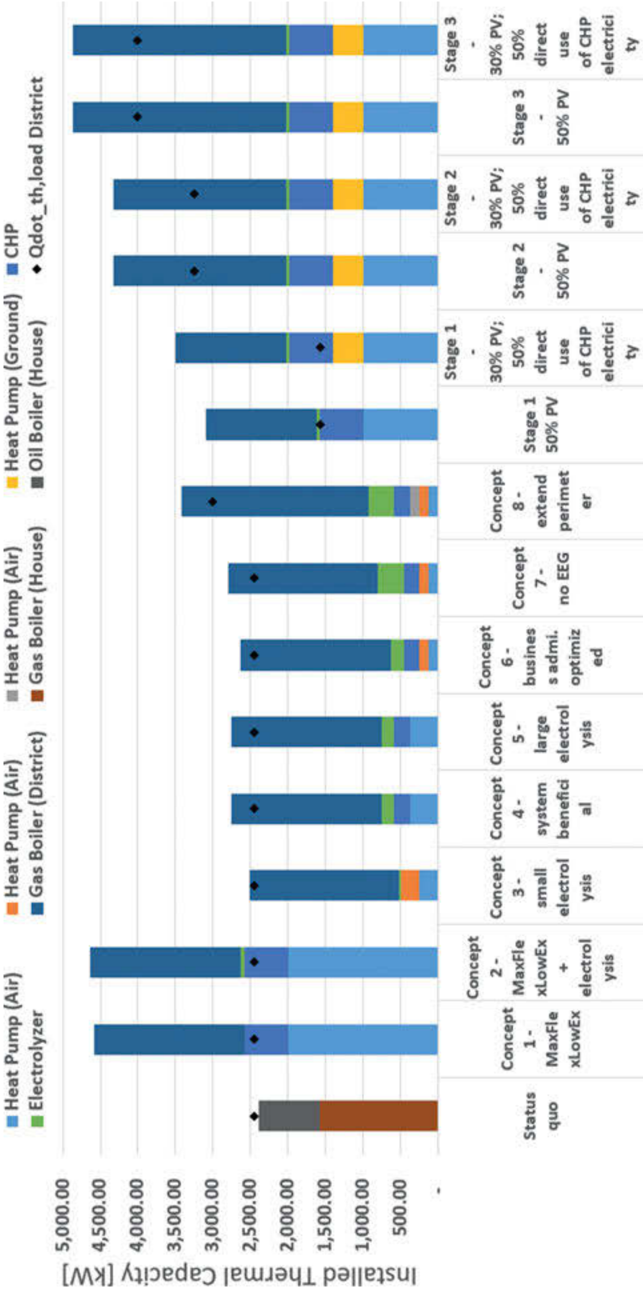

Figure 27.7: Installed capacity of individual heat generation units.

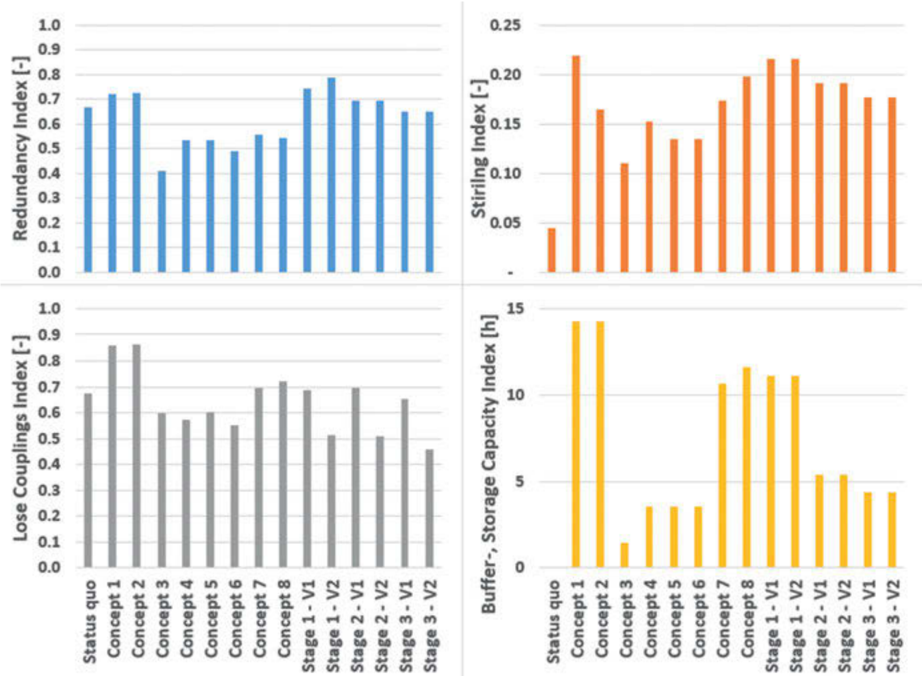

Figure 27.8: Results of the redundancy Index (top left), the Stirling index as indicator for diversity (top right), the shares of loose coupled units (bottom left) and the buffer and storage capacity index (bottom right) for the heat supply scenarios of the district.

27.4.4 Matlab/Simulink and TwinCAT for Plant Testing, Operation and Visualisation

With regard to the work in the area of modelling at the feedback control level and control simulation, the addition of the decentralised operating and display devices to the modelling chain enables system investigation also in the individual operating modes, for initial operation, failure and shutdown of individual systems, as well as the complex investigation of fault behaviour and restart after failure. With the help of these studies, a conflict-free implementation of the automation system is made possible for the realisation of the project. Furthermore, training on the later control and operation of the system can be provided before realisation to save even more time.

27.5 Conclusion and Outlook

With the increasing complexity of the national and European energy system with an increasing amount of volatile electricity generation, local energy systems and district energy systems must be operated in a system-supportive way to stabilize the overall energy system and to cause a minimum amount of CO_2 emissions. The approach shortly described in this paper shows that a model chain – as complex as it is – based on open source software development, has several benefits, that are transparency, consistent and comprehensible data or integration of external expertise through collaborative cross-institutional work for designing a district energy system. Furthermore, the results are reproducible.

Since the models are developed and fed with data, defining some standard conditions could reduce the amount of work needed to adapt the model chain to design and assess energy systems for different districts. In addition this model-chain would allow for an iterative approach to determine the effect of system-supportive districts on national or interregional energy system.

The *Deflex* model together with published input data can easily be used to reproduce future scenarios and to produce time series for the evaluation of local energy systems. For long-term scenarios with very low fossil power plants new key values are needed to evaluate energy systems as the established values as the emission factor loses their significance with respect to the design of system-supportive district energy systems. Additionally, existing scenarios can be used to include different development paths that may result from the local scenarios.

It further has been shown that the modelling of a detailed physical model in Modelica makes troubleshooting and debugging more difficult and time consuming. It needs to be evaluated whether the complex research questions, especially in resilience research, require this level of detail, or whether simplified linear models could deliver comparable results in this regard.

Especially in the areas where several different softwares are used, experience from the process industry has shown that model building and usage can only succeed efficiently if standardised information models, data for exchange and standardised data exchange processes can be used. Standardisation and norming for energy systems and plants is still in its beginnings and is therefore one of the central tasks to the next few years for effective usage in an increasingly digitalized world.

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Martin Eckhard, Jana Rasch, Martin Struve, Andreas Wojta

28 Challenges for Establishing a Municipal Heating Company from a Research Project

Summary: QUARREE100 is an innovative research project with an integrated, long-term implementation. The aim is to transfer investment-based research components into an economically active municipal heating company. A closer legal look reveals complex links between tax law, municipal law, state aid and subsidy law due to the different legal entities of the subsidy recipient for research and the heating company. These must be comprehensively assessed during the foundation process in order to avoid possible financial risks and also to maintain the QUARREE100 objective during the operational phase. QUARREE100 combines the claim to be both an example and a template for an integrated and sustainable energy supply for existing urban districts.

28.1 Introduction

QUARREE100 is an innovative research project with integrated implementation that takes on the challenge of establishing an integrated, sustainable energy supply in the heterogeneous built-up district “Rüsdorfer Kamp” in Heide. The project is divided into extensive modelling and research for the creation of an energy concept under the requirements of sustainability, resilience and system efficiency on the one hand, and implementation with a long-term oriented energy supply in the district on the other. In its special feature as a built-up district, QUARREE100 interlinks district development with regenerative energy, with redevelopment and neighbourhood management as well as with urban planning approaches. While the work on modelling and drawing up the energy concept can be assigned to research and thus to non-economic activities, the subsequent operation with the new energy supply is of an economic nature at the latest.

The network partners in QUARREE100 are not in a position to take on a subsequent operator role. This requires a third party. Following a decision by the Heide town council, the establishment of a new, independent heat supply company for QUARREE100 is being examined and initiated. The intention is to create the option of allowing other companies to participate in the municipal company at a later date in order to set it up and operate it.

Note: This technical article is not a substitute for legal advice.

Martin Eckhard, Jana Rasch, Martin Struve, Entwicklungsagentur Region Heide, Germany
Andreas Wojta, Stadt Heide, Germany

https://doi.org/10.1515/9783110777567-028

28.2 Basics

In principle, the establishment of a municipal company for energy supply is not new. What is challenging in the context of QUARREE100, however, is that, on the one hand, economic viability can probably only be achieved in the long term due to the highly innovative, technical system. On the other hand, investment funding is available for research, whereby these research components are to be integrated later into the overall economic system in the sense of sustainability. In this context, funding recipients and later operators are different legal entities. This creates a complex linkage of tax law, municipal law, state aid law and subsidy law.

It is also open whether the operator function will generally be carried out by a 100% municipal company, an external third party or a mixed-economy company consisting of a municipal company with the participation of a third party. This in turn is closely linked to public procurement law.

28.2.1 Establishment of a Municipal Company

The establishment of a municipal company is governed by the Schleswig-Holstein Trade Regulation Act (SHGO).

If the municipal of Heide wishes to engage in economic activities or participate in an economic enterprise, the provisions of §§101, 101 a, 102 SHGO must be observed. In addition, the project must be reported to the municipal supervisory authority (§108 SHGO).

According to §101 SHGO, "the municipality" may establish, take over or substantially expand economic enterprises if: (1) a public purpose is paramount, (2) the economic activity is proportionate to its capacity and that of the enterprise, and (3) if the purpose cannot be fulfilled better or more economically in another way.

According to § 101a SHGO, the production or distribution of heat as an economic activity generally serves a public purpose. According to § 101a paragraph 1 sentence 2 SHGO, the highest municipal supervisory authority is responsible for the approval according to § 101 paragraph 3 sentence 2. (Dr. Krohn/Dr. Reese/Dr. Jensen-Nissen/Thiesen 2021)

An intention to make a profit is not required. A distinction has to be made above all from sovereign activities. In terms of the Municipal Code, this means activities which, according to public law, can only be carried out by a public authority.

The municipality has the right under section 101(5) to use third parties to perform its functions.

28.2.2 Funding and Conditions of QUARREE100

The funding decision, including its general and special ancillary provisions for the Development Agency Region Heide (EARH), contains specifications for handling the investment research components after the end of the

approval period. (Projektträger Jülich 2017)[1]

This states that insofar as items exceed a value of 410 EUR in an individual case, the EARH must submit a proposal for further use to the Project Management Organisation Jülich (PtJ), which is involved by the Ministry, with the submission of the proof of use. The PtJ then decides which measure is to be taken.

The grant notice specifies the following options:

a) The investment components remain with the EARH and are used there for other scientific work.
b) The components are transferred to the Confederation or to a third party
c) The components are sold and the PtJ participates in part of the proceeds, which corresponds to the ratio of total grant to total expenditure, or the residual value of the items is compensated. (Projektträger Jülich 2017)[1]

The cooperation agreement concluded between the partners of the QUARREE100 project also regulates how the knowledge gained is to be handled, in particular whether or under what conditions it may be used by a partner or a third party for economic purposes. (EARH 2018) The latter may be relevant for the licensing of the control software, which in turn was developed by individual partners in the collaborative project.

According to this, a municipality can in principle take charge of a heat supply, such as is planned in QUARREE100, with a municipal company, provided it complies with the requirements of §101 SHGO. The prerequisite is that the municipal supervisory authority does not object to this.

28.3 Legal Provisions

In addition to the legal norms for the establishment of a municipal energy supply company for QUARREE100 described in Section 28.2 and the requirements from the law on subsidies, there are various other legal provisions of public economic and tax law that are relevant to an evaluation of the following options (Section 28.5) for the establishment of a municipal energy supply company and the transfer of the research components to it.

1 Source: Project QARREE100 internal document (not publicly available).

28.3.1 Public Commercial Law

As relevant provisions of public economic law, the requirements of public procurement law and EU state aid law are of particular importance. These must be evaluated in the context of QUARREE100 and a possible transfer of subsidised capital goods as well as a tendering of an operating task.

28.3.1.1 Requirements of Public Procurement Law

Public contracts and concessions must be awarded in competition and through transparent procedures (§ 97 (1) GWB).

Relevance of Public Procurement

The award of public contracts by contracting authorities above the EU thresholds is governed by the provisions of the Act against Restraints of Competition (GWB) and – in the case of services that are relevant here – by the Public Procurement Ordinance (VgV).

Below the EU thresholds (ABSTSH 2019) the Public Procurement Act of Schleswig-Holstein (VGSH) in conjunction with the corresponding Public Procurement Ordinance (SHVgVO) and the Sub-Threshold Public Procurement Ordinance (UVgO) are relevant. The award of public contracts with sectoral relevance by so-called sector contracting authorities is governed above the EU thresholds by the Sectoral Procurement Ordinance (SektVO) and can be carried out below the EU thresholds in a so-called freely structured procedure according to §3 paragraph 3 VGSH.

Public contracts are in principle relevant for the award of public contracts. According to § 103 (1) of the ARC, this is the case if the following conditions are met:

- the contract must be a contract for pecuniary interest, the concept of pecuniary interest being understood broadly (Pünder/ScheIIenberg),
- this must have been concluded between a contracting authority or sector contracting entity and an undertaking, and
- it must have the procurement of services as its object.

Relevance of Concessions to Procurement

So-called concessions are also relevant to procurement. Concessions – in this case limited to service concessions – are contracts for consideration by which a grantor entrusts a company with the provision and administration of services. The consideration consists of the right to exploit the services, plus a payment if necessary (§ 105 (1) GWB). In contrast to the award of public contracts, the operating risk for the exploitation of the services is transferred to the concessionaire when a service concession is awarded.

The awarding of concessions above the EU thresholds is governed (ABSTSH 2019) by the award of concessions above the EU thresholds, governed by the Ordinance on the Award of Concessions (KonzVgV), and below the EU thresholds may also be awarded in a free procedure pursuant to § 3(3) of the VGSH.

If a third party is to be commissioned by the municipality with the construction and operation of an energy supply system, as was developed in QUARREE100 for example, the selection of this third party is subject to mandatory public procurement law in accordance with the corresponding threshold values due to the clear procurement elements.

In the case of a newly founded municipal company, which is thus a subsidiary of the municipality, the procurement relevance of the operator task could be significantly reduced.

28.3.1.2 Requirements from the EU's State Aid Legislation

EU Relevance of Transmission Operations

The above-mentioned public procurement law in the narrower sense only addresses procurement processes of the public sector – not bidding activities. Asset sales and transfers of use by the public sector are subject to other competition law requirements: those of EU state aid law. The requirements arising from EU state aid law were clarified by the Commission in a 2016 notice:

If the sale of assets, goods and services takes place through a competitive, transparent, non-discriminatory and unconditional tendering procedure that complies with the TFEU rules on procurement, this transaction can be considered to be in line with market conditions – market conformity. (EU-Commission, 2016)

This means: If the recipient of the benefit is a company and the concrete inflow of assets could affect interstate trade (investment or demand competition), state aid conformity can in principle only be ensured if the exchange takes place in conformity with the market. (Dr. Krohn/Dr. Reese/Dr. Jensen-Nissen/Thiesen 2021)

Particularly with regard to the question of the transferability of the research components ("service") to a third party or a municipal enterprise ("recipient") and the consideration to be provided in the course of this, there is a high relevance to EU state aid. This can be countered by ensuring that the exchange of services conforms to the market, e.g. in the form of a regular tender or company evaluation. (Dr. Krohn/Dr. Reese/Dr. Jensen-Nissen/Thiesen 2021)

28.3.2 Tax Law

With regard to the question of the transferability of the research components to a (municipal) company, various aspects of tax law must also be taken into account in any case. If benefits flow freely to a company, the circumstances and effects of this transfer must be examined carefully and the resulting tax obligations must be observed. If tax aspects come into play, it can be assumed that these will then have an effect on the investment costs and thus also, depending on the amount, directly on consumer prices.

28.3.2.1 Gift Tax Law

Although it is possible in principle, with the consent of the PtJ, to transfer the investment research components to a third party in accordance with the conditions of the Development Agency's Heide Region grant notification described in Section 28.2.2, the Inheritance and Gift Tax Act stipulates that every free gift inter vivos, insofar as the recipient is enriched by it at the expense of the donor, is deemed to be a gift inter vivos (Section 7, paragraph 1, sentence 1, Inheritance Tax Act). According to §9, para. 1, sentence 2, a tax arises on this.

Transfers of assets between public administration bodies free of charge are typically not covered by this provision; they are regularly not made freely. Due to the fact that the executive power is bound by law, it can usually be assumed that public administration bodies act in the performance of their duties and thus not freely. The transfers of assets are regularly offset by the fulfilment of the tasks incumbent on the public administration agencies. (BFH 2014).

The only decisive factor is the link between the transfer of assets and the performance of public duties, which may also be at the discretion of the donating body.

In its ruling of 29 March 2006, the Federal Finance Court (BFH) decided that these principles also apply to a gratuitous transfer of assets by a district to a limited liability company of which the district is the sole shareholder. If the transfer of assets is made by the district for the fulfilment of its public duties, the donation is not gratuitous´. (BFH 2006) As a result, this is not only conceivable between public administration bodies, but also for transfers from a public administration body to a private legal entity.

The same would apply if the EARH procured research components and transferred them to a third party or to the municipal company for the supply of the neighbourhood with renewable and affordable energy, since at that moment it would be fulfilling its tasks and thus no generosity would be apparent.

28.3.2.2 Income Tax Law

Pursuant to Section 1 (1) no. 6 KStG, commercial operations of legal persons under public law are subject to corporate income tax. According to the legal definition in § 4 (1) KStG, commercial operations are established by institutions that serve a sustainable economic activity to generate income – outside of agriculture and forestry –, stand out economically within the overall activity of the legal persons and do not constitute sovereign enterprises according to § 4 (5) KStG. (Bürstinghaus)

A legal person under public law therefore establishes a business of a commercial nature if the following facts are cumulatively fulfilled:

- Sustainable activity
- Economic activity
- Revenue generation
- Economic stand out within the overall operation
- No asset management
- No sovereign activity
- No agriculture and forestry

For an income tax assessment, it must therefore be evaluated whether the activity of the EARH as a procurer and transferor of the research components in relation to the coordination of the QUARREE100 project constitutes a business of a commercial nature.

This, in conjunction with the precise tax classification of the transfer of the research assets, would make it unlikely that income tax would be due in the event of a gratuitous transfer to a third party. If the transfer of the EARH were to take place to a (related) municipal company, where the sponsors are the same, it could be expected that the income tax would be due.

The determinant described above thus determines all income tax legal consequences.

28.3.2.3 Value Added Tax Law

By Article 12 of the Tax Amendment Act 2015 of 02 November 2015, the

Entrepreneurial status of legal persons under public law fundamentally changed. In the process, § 2 paragraph 3 UStG – the restrictive link to the KStG – was repealed and § 2b UStG was newly inserted. The amendment came into force on 01 January 2017 with an extended transitional period until 31 December 2022. As of 1 January 2023, legal persons under public law are only not deemed to be entrepreneurs within the meaning of VAT law if they carry out activities that are incumbent upon them within the scope of public authority.

In this context, it cannot be assumed that the transfer is subject to VAT, since if VAT had been due in the course of the transfer, the entitlement to deduct input tax would also have existed and the amounts would have been due in the same amount. (Dr. Krohn/Dr. Reese/Dr. Jensen–Nissen/Thiesen 2021)

28.3.3 Civil Law

28.3.3.1 Possession

The owner of a thing is the person who owns a movable or immovable thing. The essential regulations on possiession are found in §§ 903–924 BGB. This is relevant for the evaluation of the design options that assume a transfer of ownership of the components (see chapter 28.5).

28.3.3.2 Ownership

Compared to the owner, the possessor of an object is the person who can actually exercise control over the movable or immovable object at the moment (§ 854 BGB). The owner thus has the power of disposal. The main regulations on ownership are found in §§ 854 to 872 BGB. Possession may only be used within the limits set by the owner.

This differentiation from ownership (see chapter 28.3.3.1) is also decisive for the design options (see chapter 28.5), in which no ownership transfer is described, but only a transfer under ownership law, e.g. in the case of lease models, thus keeping the research components in the ownership of the EARH.

28.3.4 Conclusion on Legal Design

For projects such as QUARREE100, which in addition to scientific research approaches also provide for investment funds for their demonstration and thus real implementation in an existing neighbourhood by the public sector, it is crucial to deal intensively with the legal determinants of long-term ownership and operation of the demonstrators in order to secure the future of the facilities and thus achieve sustainability of the research without a central profit motive in real space. The decisive factor here is the condition that the public sector does not seek long-term ownership and cannot afford to operate the facilities, so that a third party (e.g. private sector or municipal company) must take over these tasks. Depending on the recipient of the research components to be transferred and the planned operator model, this must first and foremost be possible under funding law. Subsequently, the prerequisites under public procurement law, EU state aid law and tax law must be examined for the transfer process. For QUARREE100 it can be stated that the incurrence of additional taxes in the event of a transfer is considered very unlikely, EU state aid law in the context of public procurement law is challenging but can nevertheless be solved, and municipal law also provides the option for a newly founded company to be responsible for the research components in municipal hands. Further explanations on the assessment of the financial risks arising from the above-mentioned determinants can be found in chapter 28.5.3.3.

Since the legal effect depends heavily on the relationship (under company law) between the actors (here EARH and third party or municipal enterprise), no generalisation can be made at this point. However, it can be stated that the determinants leave a lot of scope for development and design and thus do not represent “show stoppers” as such.

28.4 Regional Decisions

28.4.1 QUARREE100 Network

With the unanimous decision (Eckhard 2019)[2] of the QUARREE100 partner assembly on the technical concept and its implementation for the entire built-up district, there is at the same time the challenge that the investments granted to the EARH (“Property 1”) are not sufficient for this. This means that further investments (“Property 2”) have to be borne.

For local anchoring, the local partners come into consideration first and foremost (see Figure 28.1): EARH as a subsidiary of the municipal of Heide, Stadtwerke Heide as a subsidiary of the municipal of Heide and the municipal of Heide. However, in order not to define the possibilities too narrowly, the option of a third party is also touched upon. The various design options involving the actors mentioned here are examined in chapter 28.5.

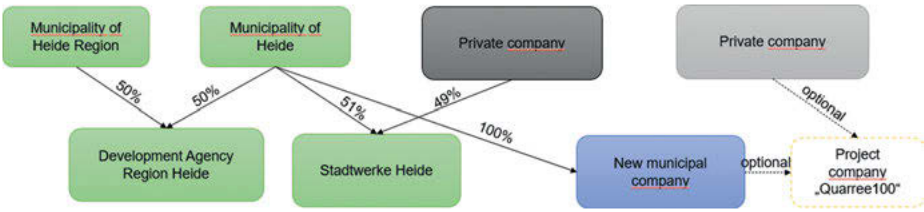

Figure 28.1: relationship of Stakeholder.
(source: own illustration)

28.4.2 Development Agency Heide Region

EARH was the project initiator and is responsible for the overall coordination and implementation of the research project. Since its original tasks are in the field of economic development and the promotion of cooperation between the city and the

2 Source: Project QARREE100 internal document (not publicly available).

surrounding area, EARH will not take over the technical operation of the energy system after the end of the research project, nor will it take on any further investments in the context of QUARREE100.

The EARH would like the investment research components to be handed over to the potential operator after the end of the project with the obligation to implement the objectives of QUARREE100 and to continue to pursue research approaches in the long term in the sense of a real local laboratory.

There are no plans for the EARH to participate in an energy supply company in Rüsdorfer Kamp.

28.4.3 Municipal Utility Stadtwerke Heide

Stadtwerke Heide is a partner in the QUARREE100 project and a 51% subsidiary of the municipal of Heide. As a local energy supplier, an active role in the realisation and operation has therefore been intensively discussed. Within the framework of a supervisory board resolution, it was decided that Stadtwerke Heide would neither assume the operator function nor make additional investments for this purpose. (Sieber 2021)

28.4.4 Municipal of Heide

The council of the municipal of Heide considers the goals and orientation of the project to be important and decisive for a climate-friendly heat supply. It therefore gives the city administration a mandate to examine the establishment of a municipal heat supply company for QUARREE100. (hps 2021) This company can be 100% municipal or structured as a mixed-economy company.

28.4.5 Private Sector

Since the municipal of Heide does not yet have its own heating company, the participation and cooperation of a third party that can contribute know-how and experience is also being considered.

28.5 Design Options

With regard to the design of a solution for the operation of the innovative energy supply of QUARREE100, both the corporate law structure of the company to be founded and the intended transfer of the research components must therefore be considered.

28.5.1 Corporate Law Structure of the Supply Company

The energy supply company for QUARREE100 can either be a 100% company of the municipal of Heide (public company), a mixed-economy company with the public shareholder City of Heide together with another company under private law, or a purely private-law company of a third party.

28.5.2 Transfer of the Components

The transfer of the possible components of the EARH to the energy system can be carried out either within the framework of a divestment model (with transfer of ownership) or a lease model (without transfer of ownership) according to Section 28.3.3 both models in turn can take place in return for payment or free of charge.

In order to secure the project's objectives in the long term, the respective form of this transfer can be designed with or without conditions for the assumption of operator obligations.

28.5.3 Scenarios

With regard to the open options concerning the transfer of the investment research components of the EARH as well as the corporate structure, there are a variety of scenarios, which in turn are complex with regard to the legal aspects of item 2 and item 3 and must be comprehensively evaluated. The aim is to avoid possible financial risks and to maintain the objectives of QUARREE100.

In order to securely maintain the objective of QUARREE100, it appears necessary that a sufficient operator obligation is also formulated with a transfer of the components.

28.5.3.1 Evaluation of the Corporate Law Structure

Public Society

The establishment of a public company in the context of district energy supply is measured according to §§ 101, 106 a SHGO. The process requires a long-term positive economic plan to fulfil the requirements of the economic principles according to § 107 SHGO and thus for approval by the municipal supervisory authority, as well as a willingness to invest on the part of the municipal of Heide, which must be decided by the political bodies.

The prerequisite for opening the scope of application of §§ 101, 108 SHGO is the existence of an economic activity. Such an activity is assumed if services or goods are continuously and systematically offered on the generally accessible market. (VG Ansbach 2005) An intention to make a profit is not required.

Due to the public sponsorship, the objectives of the project can also be directly included in the company statutes, in particular also under the aspect that the municipal of Heide is an association partner and has thus also signed the project's own cooperation agreement with regard to the rights of use.

Advantageous: Fulfilment of conditions under subsidy law, in particular for the assumption of operator obligations, no sustainable operating profit has to be achieved.
Disadvantages: No operational experience on the municipal side, long-term start-up process, public willingness to invest necessary.

Since the local municipal utility has rejected the operator and investor role, but the city is nevertheless striving to implement the project, the establishment of a new municipal utility company is being pushed. This path is ultimately open to every municipality, as long as this company meets the requirements (see chapter 28.2.1). It provides comprehensive scope for influencing and shaping the local promotion of an affordable energy transition and sets the tone for political decision-making with regard to the future development of a municipality.

Private Company

By transferring the project to a private company, an experienced company could be gained which, through its expertise in implementation and subsequent operation, would achieve cost savings, e.g. through synergies with other projects, corporate structures or other activities in the segment. On the other hand, taking over the operator duties in the context of achieving the goals of QUARREE100 appears attractive only to a limited extent if this is not accompanied by sufficient profitability. In order to consolidate the business foundation, this can lead to private-sector companies not fully implementing the technical concept in the research sense.

Advantageous: Experienced companies possibly with synergy opportunities, no public investments – private sector risk
Disadvantage: Difficult contractual assurance of QUARREE100 target achievement commitment.

Mixed Economy Company

A mixed-economy company could combine the advantages of both previous possibilities. Nevertheless, the establishment process is much more complex, since the participation of a private company in a public company can already be relevant for the award of contracts. In addition, the shareholding ratios must be coordinated.

Advantageous: Public shareholder can ensure the interests of the city, private shareholder can contribute experience and synergies.

Disadvantages: High coordination effort in the foundation with regard to tasks, investments and company shares. Private-sector participation can be relevant to procurement.

Solution Approach for QUARREE100

When considering the pure implementation ("operation") of QUARREE100, a purely municipal company is favoured. However, the option of a mixed-society solution is not out of the question. In the case of a purely municipal implementation option favoured by the municipalities, a strict implementation period specified by the project would result in a greater weighting of the disadvantages mentioned, especially with regard to the establishment process and operating experience. This can be overcome by a private-sector partner. The perspective of participation by the municipal company should be given here.

If precisely these limiting factors (timeshedule, know-how) are not decisive, the path via a newly founded municipal company can be pursued further.

Irrespective of the special funding context and the importance of QUARREE100, the local public utility or a private sector company is usually used for the implementation of such supply concepts, so that a municipality does not have to deal directly with the realisation of an energy supply itself.

28.5.3.2 Evaluation of the Conditions of the Grant Decision

In principle, the funding decision evaluates the investment funds analogously to the funding of research equipment. These investments are funded at 100% under the aspect of research funding and are not subject to a commitment period. However, in accordance with Section 28.2.2, at the end of the project, the project management organisation must be informed of how these investments will be used. The focus here is on further use in the sense of research, i.e. sufficient access to research should be maintained in any case.

This can be done, for example, as part of a long-term validation of the technical system with an evaluation of the modelling. Furthermore, it is possible to use the research components in thematically related projects in the Heide Region, such as SYSTOGEN100 or WESTKÜSTE100, or in the university-based education of students at the West Coast University of Applied Sciences in combination with the new teaching and exhibition building.

If income is generated with the project within the project term, this would have to be offset against the funding. (AnBest-P 2016)

Advantageous: No commitment period with 100% funding, further possible use in terms of research is available also with participation of EARH.
Disadvantage: Final decision is incumbent on the PtJ or the approving ministry, with a binding statement only after the end of the project.

28.5.3.3 Evaluation of Financial Risks

The financial risks that may arise from a transfer of the research components from the EARH to a third party and from the legal aspects mentioned in chapter 28.3 can be minimised as follows:

Award of Public Contracts

The procurement regulations for public contracts must be applied to procurements in accordance with the specifications in Section 28.3.1.1. The public procurement law of the anti-trust law regulates the procurement of services above the EU thresholds by contracting authorities. It therefore only covers cases in which contracting authorities act as purchasers of services above the EU procurement threshold.

Circumstances in which the EARH offers services as a provider on the market are at most subject to EU state aid law (see below). However, caution is required if a sale, rental or leasing transaction imposes ancillary obligations which have procurement character (so-called “encapsulated procurement transactions”). Unless these are completely subordinate, they infect the contract, which is actually contract-exempt, and turn it into a public contract relevant for award. (Pünder/Schellenberg) This could be the case if the investment components take place under the condition to take over the operator obligations.

However, insofar as the components are owned or possessed by the EARH to a public company of the municipal of Heide (as one of the shareholders of EARH), this is not relevant to the award. This is because public contracts awarded by a controlled legal entity which is also a contracting authority within the meaning of the restrictions of competition Act (GWB), § 99 No. 2 GWB (EARH) to another legal entity controlled by the controlling contracting authority (the municipal of Heide) are not relevant for award (§ 108 (3) GWB) (Hofmann 2016).

If a transfer from the EARH to private sector actors – including mixed-economy actors – is to take place, an extensive procurement procedure for the heat supply will most likely be necessary with regard to procurement regulations.

Advantageous: Transfer to public company of the municipal *of Heide*

Award of Concessions

The award of a concession is necessary if the future operator or owner acts under his or her own economic responsibility (§ 105 (1) GWB). The concession then includes permission to supply heat to the district in the city, possibly linked to rights of way. As this is not the sovereign task of EARH, but lies with the municipal of Heide, any transfer to a private company would be complex and a trilateral agreement between EARH, the municipal of Heide and the concessionaire would have to be put out to tender.

Advantageous: Transfer to public company of the municipal of Heide

EU State Aid Law

EU state aid law must be considered in particular if, as a result of a transfer of the investment funds, an economic enterprise receives a market-economy advantage through a subsidy, i.e. the components are made available free of charge or at non-market conditions and the EARH can no longer fulfil its obligation to use the components for research. This must be carefully examined and a valid argument must be made in the case of possible aid.

Advantageous: Sale for a consideration at market price or free lease model with guarantee of earmarking on the research side by EARH as owner

Gift Tax Law

Gift tax applies when investment components are transferred to a third party free of charge as property of the EARH.

Advantageous: Sale against payment at market price or lease model, so that the EARH remains the owner.

Income Tax

Income tax liability is to be expected if the components are sold by EARH at a profit. It is not clear whether a profit will be made, as the income would have to be transferred to the funding agency in accordance with Section 2.2, paragraph 2, (c). (Projektträger Jülich 2017)

Advantageous: Transfer free of charge

Sales Tax

Turnover tax is to be expected if the EARH generates turnover with the components. These can arise from sales or leasing.

Advantageous: Transfer free of charge

28.6 Design of a Concrete Implementation Model Operator Model within the Framework of QUARREE100

For an organisationally efficient operation of the energy supply system to QUARREE100, it appears important that, while maintaining the objectives of QUARREE100, the economic operation is transferred into one hand at the end of the project.

In this context, the investment components of QUARREE100, together with other investments, are to represent the technical energy supply system. Furthermore, it is important to maintain the objectives of the research project with the developed technical and climate-relevant objectives of the technical system, which means that with the transfer of the investment components from QUARREE100, an operator obligation is also established in this regard.

Model I

Based on the preconditions described at the beginning (in particular, EARH procures research components and makes them available to an operator or transfers them) and on the large number of possible transmission variants, the following implementation recommendation would be considered, taking into account the scenarios described in Section 28.5 and their evaluation:

- Foundation of a public company for energy supply in QUARREE100 by the municipal of Heide
- Free lease of the investment research components from EARH to the new municipal company. The EARH thus remains the owner and continues to guarantee research access to the investment components from QUARREE100.
- Use of the work results achieved from QUARREE100 within the framework of the cooperation agreement by the municipal of Heide
- Procurement and construction of the other necessary components for the energy system by the new company. For this purpose, the company should obtain further funding. The total financing could be provided, for example, by a shareholder loan from the city, a loan with a guarantee from the city, or a financing concept consisting of both.

This implementation model seems to be the best way to fulfil the requirements of the law on subsidies and the simplest way to fulfil the requirements of the law on public procurement, as well as to minimise the possible tax obligations.

Model II

Due to the increasingly strict timeline and the ongoing foundation process, the implementation recommendation outlined above had to be re-evaluated and finally further developed. For a quick realisation of the project goals as well as preservation of the granted subsidies, the path is now taken via a mixed-economy company:

The city is sticking to the foundation of a new municipal energy supply company. For a quick and competent realisation of the project goals, which cannot be achieved by the municipal company alone, a private partner is to be involved. This partner is to be sought on the market at the initiative of the project and entrusted with the task of implementing the research approaches, e.g. via a separate project company. To ensure this, this actor should become part of the project with its own role and budget responsibility and thus a partner in the project consortium. The search for this third party can take place, for example, through an open approach to potential companies to determine concrete expressions of interest in the implementation of QUARREE100 and cooperation with the municipal company. This opens up the possibility for a municipal company to participate in a project company of the private actor at a later stage (duration of the foundation process) in order to secure the municipal interests and influence.

If both companies are finally partners in the project with their own role, the set project goals of QUARREE100 could be implemented in consensus with the consortium, the work results already achieved could be used jointly to realise the goals and the necessary research components could be procured together with the private partner.

This differentiation from ownership (see chapter 28.3.3.1) is also decisive for the design options (see chapter 28.5), in which no ownership transfer is described, but only a transfer under ownership law, e.g. in the case of lease models, thus keeping the research components in the ownership of the EARH.

28.7 Final Consideration

It should be noted that the transfer of the research project, particularly with regard to the subsequent systemic integration of the investment research components into an economic supply system, raises complex legal issues that were not apparent to this extent when the application was submitted and approved.

It is important that with a final decision to found the public energy supply company for QUARREE100, a first building block is established around which all other circumstances for the transfer and use of the research components as well as the overall operation for the sustainable supply in the built-up district can be arranged. An open multitude of possibilities fundamentally inhibits the decision-making process.

It is also evident that in the context of public procurement and tax law foundation processes, decisions by local politicians and the necessary preparations by the administration have to be planned more comprehensively in terms of time than is to be expected in the private sector.

Even if a number of scenarios have already been considered here, it is urgently recommended that the formation and transfer processes be resolutely accompanied under the legal requirements outlined. Particularly in the context of tax law, legal support will be able to adequately assess the possible obstacles, but will not be able to provide clear certainty, as ultimately discretionary decisions by the tax authorities cannot always be clearly determined in advance.

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Joris Zimmermann, Gunther Gehlert

29 Design and Integration of Large Heat Pumps for District Heating with heterogeneous building structures

Summary: The project Quarree100 aims to implement a district heating system at the Rüsdorfer Kamp in the city of Heide. This publicly funded project has set ambitious targets for certain criteria such as innovation, renewability, resilience, transferability, acceptance and economic efficiency. In the following, an overview of the design process and results is provided, highlighting the requirements and integration of large heat pumps in such a district with heterogeneous building structures in terms of age, typology and utilization.

29.1 Introduction

The renewable heat supply to buildings is one of the major challenges of the transition of the energy system. In Germany, buildings currently emit approx. 120 million tons greenhouse gases per year (Umweltbundesamt 2021a), which is above 16 % of the total emissions in Germany. In contrast to the energy sector, the transition in the building sector is rather slow: the reduction had been 1,9% per year between 1990 and 2020. More importantly, the emissions remained rather constant since 2014 (Umweltbundesamt 2021a). The reasons for the slow progress are mainly cost-driven. Fossil fuels like natural gas stayed at very low prices whereas electricity prices went up continuously, mainly driven by government-induced taxes and fees. As a consequence, buildings and districts have been increasingly supplied by combined heat and power (CHP) plants, because this technology makes use of the price difference of fossil gas and electricity.

When focusing a renewable future energy system, the main question is how to substitute fossil fuels in heat supply of buildings. The solutions currently discussed are as follows:

1. Reduce heat losses by thermal insulation
2. Combustion of biomass, e.g. wood pellets

Acknowledgements: On behalf of the Quarree100 project team, the authors would like to thank the Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung) and the Project Management Jülich (Projektträger Jülich) for the funding and support.

Joris Zimmermann, Steinbeis-Innovationszentrum energieplus, Hamburger Straße 277, 38114 Braunschweig, Germany

Gunther Gehlert, Fachhochschule Westküste, Fritz-Thiedemann-Ring 20, 25746 Heide, Germany

https://doi.org/10.1515/9783110777567-029

3. Increasing installations of electric heat pumps (powered by renewable electricity)
4. Combustion of biogenic or artificial gases, e.g. biogas, hydrogen or artificial methane

Remark to item 1.: In the past years, the German government had enacted laws with increasing strictness regarding new buildings to make sure that newly built houses do emit lesser and lesser greenhouse gases. (bmwk 2007; 2009; 2020) However, the major problem occurs when looking at existing/old buildings. Due to the right of continuance, owners of old buildings cannot be directed to modernise their houses. Hence, very little thermal insulation is done, mainly because it is expensive and amortisation times are very high (often longer than 15 years). In summary, the modernisation rate of existing buildings stays in the range of 1% per year and the heat supply of old buildings is the real challenge for the renewable transition in the building sector.

Remark to item 2.: The combustion of wood or pellets is truly renewable to an extent of approx. 80 to 90%, only. One reason is the upstream processing (harvesting, crushing, milling, transport etc.). Another reason is the auxiliary energy in pellet boilers (electrical ignition and transport). Moreover, the availability of sufficient amounts of biomass is the main challenge. In regions with extensive forestry (e.g. Austria), wood or pellet boilers are widely spread. However, in other regions, the extensive use of wood or pellets would lead (1) to a "food or fuel debate" and (2) to increasing commodity prices.

Remark to item 3.: On the one hand, the operation of electrical heat pumps is closely connected to the progress of the renewable transition in the energy sector. For a completely renewable heat supply, it has to be presumed that the electricity is fully renewable. On the other hand, it has to be mentioned that heat pumps utilise ambient heat (anergy, renewable energy) to a high extent. Therefore, installing an electrical heat pump offers a benefit independently from "green" electricity. However, operating costs (especially in poorly insulated old buildings) are usually higher because prices for fossil natural gas or oil are much lower than electricity. This situation will change as soon as larger amounts of artificial "green" gases will be injected into the gas supply. This process is currently accelerated by drastic disruptions in the energy sector and policy changes to the German EEG.

Remark to item 4.: With focus on biogenic gases, also a "food or fuel debate" will start, if these gases are produced to a larger extent. When looking at artificial gases like hydrogen or artificial methane, it is obvious that these fuels are more expensive (per kWh) as the renewable electricity (and much more expensive than heat generated by heat pumps), which is used to produce these gases. The reasons are (1) higher opex costs due to efficiency factors in the processes electrolysis and methane synthesis and (2) additional capex costs for the required installations. Therefore, it can be stated that heating with (partly) artificial gases is only beneficial during a transition period, when a large fraction of the distributed gases is still from fossil origin.

In terms of establishing a renewable heat supply for mixed zones with heterogeneous building structures, planners face an additional important constraint: since the thermal insulation in older buildings is rather poor and floor heating is almost nonexistent, the required heating temperature is expected to be significantly higher than in newly-built homes. The demand for these high heating temperatures is a significant obstacle in terms of cost-efficient use of heat pumps. On the other hand, biogenic materials are too scarce in northern German regions in order to use them for heating on a larger scale. Thirdly, comprehensive thermal restoration of these old buildings would be even more expensive than a rather inefficient use of heat pumps.

As a consequence, one of the main challenges in the "Quarree100" project (Entwicklungsagentur Region Heide 2019) has been finding a compromise between cost-efficiency and minimal emission of greenhouse gases when establishing a heating concept for this mixed zone with a significant fraction of old buildings.

29.2 Project Quarree100

The project Quarree100 is concerned with the district "Rüsdorfer Kamp" in the city of Heide, in northern Germany. The project aims to design and realize a cellular, multimodal, resilient and sustainable energy supply system for the existing and prospective buildings in this district.

29.2.1 Data Acquisition in the "Rüsdorfer Kamp"

The district shown in Figure 29.1 is inhabited by approximately 500 people of diverse age structure. Most buildings are single-family homes, multi-family homes are in the minority. There are only a few non-residential buildings that can be mostly classified as businesses, not as industrial buildings. A comprehensive energetic evaluation of these existing buildings was one of the first challenges in the work package tasked with designing the energy system. Fortunately, the project team was provided the gas supply accounting data by the local municipal utility company. This proved valuable in determining the key customers with the highest energy demand, both within and outside the boundaries of the originally defined district. Early in the project, this led to an extension of the district, to include for example the regional administration office in the proximity, with an annual heat demand of about 20% of the remaining Rüsdorfer Kamp. Acquiring those key customers had been made a priority early on. All in all, information such as floor area and number of floors, thermal and electrical energy demand, inhabitants, roof area, slope and direction information were gathered for each individual building. Since most of this data underlies the protection of privacy, all data has been anonymised. The resulting data base provides the basis for all energy demand calculations as well as potential analysis of photovoltaic installations.

All simulations of energy systems require timeseries data of all relevant input, such as weather, energy demands and supply, and energy market statistics. Weather data is gathered from DWD (Deutscher Wetterdienst 2017), energy demand timeseries are based on normalized load profiles from various sources and scaled to the historical annual energy demand, as outlined in (Röder/Meyer/Krien et al. 2021). This supply of local photovoltaic yields is simulated with TRNSYS (TRNSYS 2019), based on the data in the building register.

Figure 29.1: Register of the buildings in the district Rüsdorfer Kamp.

29.2.2 Design of an Energy Supply System

For designing and choosing an energy supply system for the district, certain criteria were defined:

- Innovation (using innovative technologies)
- Renewability (including reduction of carbon dioxide emissions)
- Resilience (against internal and external disturbances)
- Potential for service to the electricity grid
- Transferability (of the system design to other districts / cities)
- Acceptance (among the local population)
- Economic efficiency

Figure 29.2 shows the energy supply system resulting from this design process.

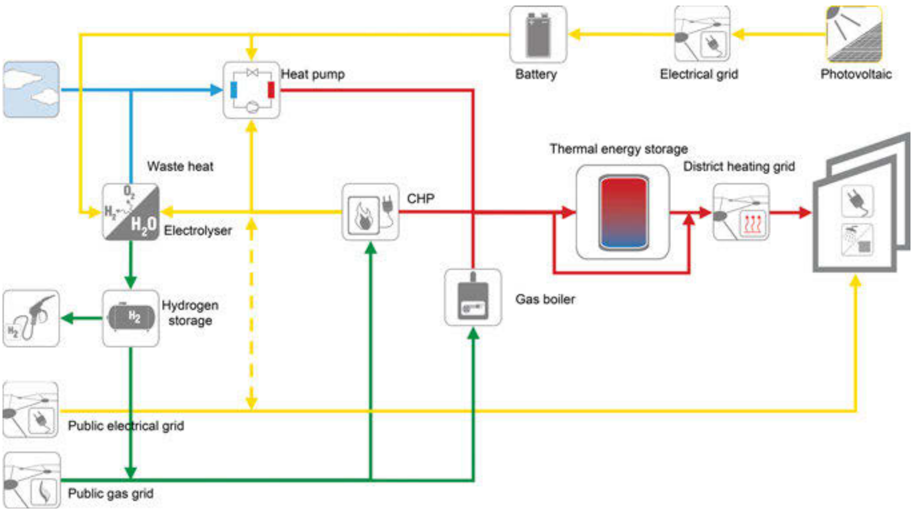

Figure 29.2: Outline of the district heating system.

Renewable energy is collected with photovoltaic panels. Since there is no dedicated area to install them on, they are instead distributed over the roofs of the residential buildings. Due to regulatory reasons and to keep electricity costs as low as possible, a dedicated electrical grid must be installed and used to collect the electricity. Otherwise, the photovoltaic yields would have to be fed into the public grid, thereby sold, and then bought back. Instead, this dedicated grid (called “Betriebsnetz” in German) would be installed in parallel to the public grid and effectively consist of a collection of direct lines from each photovoltaic installation to the energy control central. Such a grid installation, crossing public streets, poses various regulatory challenges and would be among the first of its kind. It is therefore one of the most innovative elements of the concept and could represent a precedent for other use cases of this kind. In the energy control central, a battery is used as a short-term storage for the collected renewable electricity.

A high temperature air/water heat pump is the primary heat generator, which is powered by either the photovoltaic power, by the power from a combined heat and power unit (CHP) or by the public electricity grid. The latter is an important option for further CO_2-reductions and will be discussed in Section 29.2.4. Electricity can also be used to produce hydrogen in an electrolyser, which is installed for research and demonstration purposes. Hydrogen use can be tested in the CHP in combination with natural gas, potentially used for hydrogen mobility or fed into the public gas grid. The electrolyser's waste heat can be used for heating, but only if the temperature is raised further. To achieve this, the waste heat can become a source for the heat pump. However, the available thermal power from the electrolyser is very small compared to the demand of the heat pump. Therefore, the ambient air remains the heat pump's main source and the system is not dependent on the electrolysis, making the concept more easily transferable. The CHP is the secondary heat generator and, finally, a gas boiler is used as a back-up heater. The produced heat can be stored in a large water heat storage of about 500 m^3 that can provide heat for several days of use. The heat is then transported to the buildings via a district heating grid. The heat transfer stations in each building could potentially be equipped with smaller decentralized heat storages. These could decrease the peak thermal load in the heating grid. Due to higher investment cost, however, they currently are not a fixed component of the energy system.

Heat pumps (at this scale) and electrolysers are innovative technologies. Using local solar energy or grid power with a low CO_2-emission factor allows for a renewable system and the reduction of CO_2-emissions. The combination of several heat sources provides resilience against disturbances of various kinds. The system can potentially provide support for the public electricity grid. It can supply electricity to the public grid, as well as draw an additional load, depending on the current requirements. This can help to stabilize the public grid or use power that might otherwise have to be discarded. Since this energy system is being integrated into an existing city district, chances are high that the concept can be transferred to other places. The seamless integration, comfort of district heating and potential for long term stable energy prices are key factors for the acceptance of this project. Due to all these benefits however, the economic efficiency of the concept is the hardest criterion to fulfil.

Many other alternative system designs were considered but discarded. For example, larger electrolysers were deemed unfeasible due to the lack of demand for hydrogen. Analysing the potential for geothermal energy as a source for the heat pump showed that the available area for boreholes could not deliver enough energy output, and such a system would not be as easily transferable as an air source system. Larger energy storage capacities, both thermal and electrical, had to be cut due to costs. Decentralized heat pumps for each building would not be as resilient and provide muss less potential for service to the electricity grid.

29.2.3 Considerations for Integration of Heat Pumps

Technically, the heat pump is the most challenging component. While smaller heat pumps with lower flow temperatures used in modern buildings have been established for many years, the presented concept has more demanding requirements. The supplied buildings are from different time periods and mostly several decades old. Supplying the heat via a heating grid with its inherent heat losses further raises the required flow temperature. The heat storage adds an additional requirement. Available thermal energy is defined by the usable temperature difference. To store the highest possible amount of heat in a given water volume, a relatively high temperature must be achieved. For times when the storage is supposed to meet the full demand of the grid on its own, it can only do so while its outlet temperature surpasses the set temperature of the grid.

As a result, air/water heat pumps for this concept must raise the temperature of the heat source (environmental air) to at least 80° C, while providing thermal output power of 1.000 to 2.000 kW_{th}, depending on the final size of the heating grid and the targeted share of the heat pump (in relation to the CHP). Heat pumps suited for these operating conditions are no of-the-shelf products yet, but instead designed for each use case. Due to the large temperature difference between source and load, manufacturers use a two staged process of either screw or piston compressors. The most common refrigerants are R717 (ammoniac) and R1234yf. The air heat exchangers required for providing enough thermal source power need a large installation surface and create a noise level above the limits for residential areas. Therefore, noise protection barriers must be integrated into the installation concept. Ground-source heat pumps using geothermal energy have been considered as an alternative, promising higher coefficients of performance and lower noise emissions. However, exploration drilling showed that the nearby available areas for boreholes could provide only a fraction of the required annual energy demand, while increasing the investment costs drastically.

29.2.4 CO_2 Reduction Potential

The potential for CO_2 reduction is a central criterion of the presented energy concept. This potential depends primarily on the installed power and operating strategy of the heat pumps. There is a difference between an ecologically ideal and an economically viable solution. For example, due to the high investment costs, only half of the targeted heat pump power may be installed at the start of the project. With changing economical boundary conditions, upgrading to the full power may become viable after some time. Using the electrical power from the photovoltaic panels is the primary potential for CO_2-reduction. However, especially with a reduced installed power, the heat pumps will not be the sole provider of thermal energy. Instead, they will operate in conjunction with the CHP, using their produced electricity. While not ideal, this is already an ecological improvement compared to the current situation.

The critical decision in the operating strategy is when to use electrical power from the public grid. Depending on the prices for electricity and gas, as well as weather conditions, this can be more economical than using the CHP. If the current CO_2-emission factor in the public grid is then low enough, it also provides an ecological benefit compared to burning gas. It is estimated that after the start of the project, without using significant electrical energy from the public grid, about half the CO_2-emissions can be reduced in the buildings supplied by the district heating. With increasing renewable energy available in the German electricity grid, using this external electricity becomes more beneficial over the years. After upgrading the installed heat pump power when it becomes economically feasible, the complete heat demand can be supplied by the heat pump alone, powered by the combination of local photovoltaics and CO_2-neutral electricity from the grid. Today, the key is providing the necessary infrastructure for this transition.

Defining the time-dependent CO_2-emission factor of the public grid is a crucial aspect of this ecological evaluation. Due to the close proximity to large off-shore wind parks in the North Sea, it may be argued that the used electricity has low CO_2-emissions whenever enough wind power is produced, or at least when there is actual excess power in the grid and wind turbines are being curtailed. While this may be renewable electricity from a physical perspective, legally it is not. Another approach would be to simply obtain all used electricity from a provider of 100% renewable energy, who could provide a certificate of effectively zero CO_2 emissions. While it is certainly desirable from an ecological point of view (and to be legally able to sell "renewable" heat), currently this form of evaluation is still not transferable to all of Germany. In the end, the most neutral and transferable approach is to use the mean CO_2-emission factor for the whole country, as published by the German Umweltbundesamt (Umweltbundesamt 2021b), when performing annual calculations. For hourly values of the mean CO_2-emissions, sources like the "Agorameter" by Agora Energiewende (Kleiner/Litz/Sakhel et al. 2019) can be used. This way, the complete state of the German energy transition is reflected in the ecological evaluations of the district energy system.

29.2.5 Practical Planning and Implementation

A district heating system of this scope requires not only a suitable design, but also good communication between various parties, in order reach a practical realisation. Respective assignments include:

- finding a suitable site for the central heating building,
- rezoning of the land-use plan to allow the construction of the central heating building,
- dealing with other constraints, like noise protection,

– addressing the prospective key customers,
– educating the local residents about the project.

In order to finalize the design of the component dimensions, several potential expansion stages for the district heating system had to be taken into account. While the full potential of the whole district is known, it is hardly plausible that all potential customers can be connected to the heating grid. The value of a plausible connection rate depends on the expectation, assumptions and experience of the investor and operator. The expansion stage depicted in Figure 29.3 represents the latest plans.

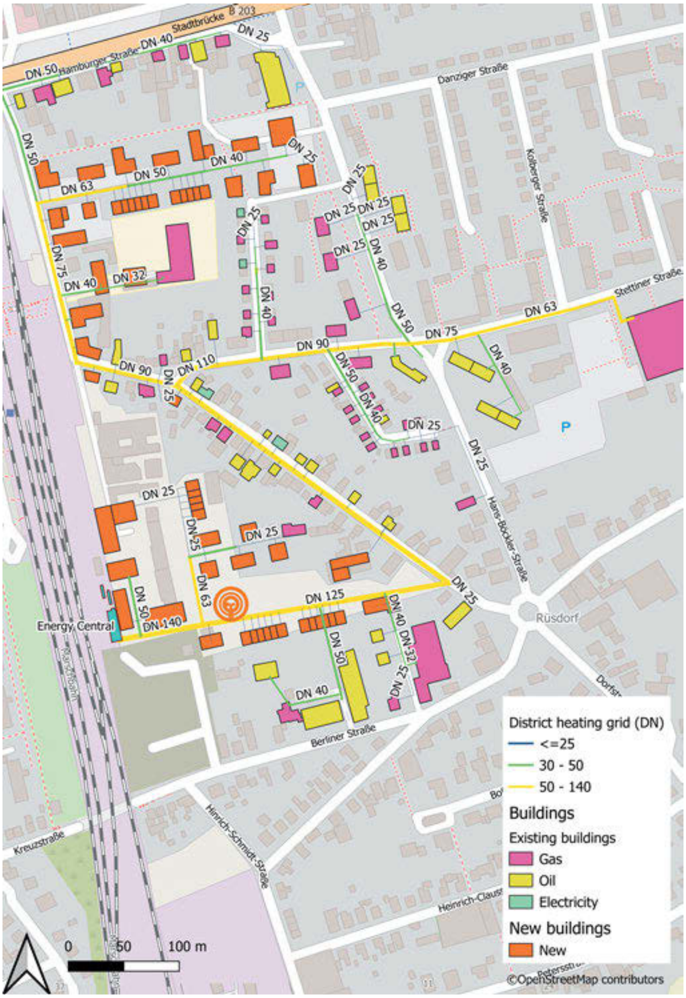

Figure 29.3: District heating grid for latest planned expansion stage.

A main line of the heating grid connects the energy central in the south-west with the regional administration office in the east of the district. Along the way, most key clients with the oldest heating systems, mostly oil boilers, are connected, but also some percentage of more modern gas systems. The heating grid branches out to allow reaching most of the buildings in the district, as well as the two areas where construction of new residential buildings are planned. These 130 buildings have a combined annual thermal energy demand of about 6.5 GWh_{th}/a and are supplied via a 5.2 km heating grid. This data allows finalizing the dimensions of the heating grid and all components of the heating central. The energy system is modelled and simulated with TRNSYS to set the component dimensions, implement control strategies, and obtain the annual energy flows.

This information enables a detailed economical calculation of all capital and operation expenditures. The resulting economic viability is, in the end, the most crucial factor and optimizing the economic result is an iterative process. Up until now, a future-proof and resilient energy system like this was inherently more expensive than the (fossil) state of the art. Recent events however, leading to drastic increases in energy prices, underline the necessity of and facilitate the transition to more sustainable, future-proof and resilient energy systems such as this.

29.3 Conclusion

For the Rüsdorfer Kamp in Heide, the project Quarree100 provides an opportunity to implement an innovative and sustainable heating system in a district with a heterogeneous building structure. Renewable heat is based on photovoltaic installations throughout the district, collected via a dedicated electrical grid, used in a central heat pump and combined with fossil CHP as well as gas boilers for resilience and flexibility of operating strategies. Powering a heat pump with renewable electricity from local photovoltaics and the public grid is the driving factor for the reduction of CO_2-emissions. Distributing the heat via a grid enables flexible operation of the central heat generators and energy storages. The modularity of the heat generation proofs to be crucial in ensuring the economic viability of the concept and helps with the transferability of the system design to other districts. Various use cases of hydrogen produced by an electrolysis can also be studied and tested. This system's design is based on extensive data collection, simulations of the energy system and detailed economical calculations. The Quarree100 project team is presenting an economically viable solution that is prepared for practical implementation. All the preliminary planning can now be turned into reality, as a key contribution to the German energy transition.

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Anne Nieters

30 Quantification of Regional Economic Effects through a Sustainable Heat Supply of a Neighbourhood

Summary: In the city of Heide (Germany) an efficient and integrated energy system in an existing neighbourhood is being developed that delivers 100% renewable power, heat and mobility solutions. In our study, we analyse the impacts on the regional value-added and employment resulting from this comprehensive transformation of the energy system. Our approach is a comparatively simple method for estimating regional welfare effects. (Kosfeld/Gückelhorn/Raatz et al. 2013) Using the example of heat supply in Heide, we conclude that positive economic effects can arise in the region largely detached from the economic viability of investments in the expansion of a decentralised supply system.

30.1 Introduction

To reach the global climate goal keeping the average surface temperature rise well under 2° C, massive changes in the way energy is produced and used are mandatory. In this context, the decentralisation of the entire energy system is becoming increasingly important. This transformation requires investments, which in turn influence regional value added and employment positively.

In the city of Heide (Germany) an efficient and integrated energy system that delivers 100% renewable power, heat and mobility solutions is being developed. The core of the system is a local heating and electrical operating grid. Photovoltaic (PV) systems installed on the roofs of the houses supply electricity directly to a large heat pump. The generated heat is temporarily stored in a large-scale heat storage unit. The battery storage buffers the PV electricity when the thermal storage is overloaded. Two different storage facilities (electrical and thermal) are used to meet two important requirements for the energy system at Rüsdorfer Kamp: Grid serviceability[1] and resilience.[2] Secto coupling is achieved by

1 Grid-serving are individual or several electrical installations (generators, consumers or storage facilities) which contribute to reducing grid costs (e.g. reduction of grid bottlenecks, grid expansion requirements or optimised grid operation management). This can be achieved through knowledge, planability or controllability of the installations by the grid operator and/or a contribution to the equalisation of the grid load (Müller/Estermann/Köppl 2018).

2 A resilient energy system is an energy system that remains functional and provides energy even under stress.

Anne Nieters, Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM

https://doi.org/10.1515/9783110777567-030

means of electrolysis. In case PV electricity is not available, the large heat pump is supplied by means of a combined heat and power plant (CHP) system. A gas boiler is used for redundancy and to increase the temperature on cold days. In this study, we analyse the potential impacts on the regional value added and employment resulting from this comprehensive transformation of the energy system.

Our approach is a comparatively simple method for estimating regional welfare effect. (Kosfeld/Gückelhorn/Raatz et al. 2013) The focus is on the transformation of the heat supply from conventional to renewable and the operation of the new energy system. Therefore, we compare two scenarios: A business-as-usual ("BAU", conventional) and a forward-looking (renewable) heat supply ("operating grid"). Based on the "operating grid" scenario, different sensitivities are investigated. The period covers 2022 to 2050.

30.2 Method

In the literature, regional economic effects of investments in renewable energies are estimated based on different approaches. (Coon/Hodur/Bangsund 2012, Jenniches 2018, Rutovitz/Atherton 2009, Wei/Patadia/Kammen 2010, Hirschl/Heinbach/Prahl et al. 2015) The concept of value creation is defined and interpreted in many different ways. (Bender/Berg/Cassel et al. 2002, Gabler 1988, Haller 1997, Statistisches Bundesamt 2003) Derived from economic theories, the concept of value creation used in this study can be interpreted as an increase in value of means of production, goods and services generated in an enterprise or a region during a certain period.

Our method of calculating value added is based on the addition of its individual components. Both, cost-effective-analysis of the production factors used and the income of the various actors involved in the transformation process form the basis (e.g. taxes, interests, profits). In addition to the value added effects resulting directly from economic activities in the transformation process (e.g. plant installation), indirect effects are also taken into account. These result from the demand for intermediate inputs and services by companies in the same or a different economic sector and describe the effects that arise at upstream stages of the value chain. Examples include services in the area of tax consulting or insurance, or the material required to repair a plant. The costs consist of income and material costs. As these two components contribute to the value added to different degrees, the shares of income or material costs for the different cost items (e.g. administration, maintenance and repair, etc.) are estimated and reflect the own assessments of the research team. Since not all expenses remain in the region under consideration, their regional shares must be estimated as well.

Finally, the additional value added in the region leads to an expenditure of the additional income generated by the expansion of renewables and thus triggers a multiplier process that stimulates demand in the region over several rounds and further increases regional value added. These effects are called induced effects. For this purpose, a multiplier is quantified for the region under consideration. This indicates the factor by which the value added generated by the activities in the renewable energy economy is increased after a theoretically infinite number of expenditure rounds. (Kosfeld/Gückelhorn/Raatz et al. 2013) The multiplier takes into account the propensity to consume, tax and transfer rates, and outflows from the region.

Employment effects are quantified based on industry-related employment intensities. They reflect the ratio between employees and turnover by describing how many employees are required to generate a certain turnover. Since information about the regional turnover are available, the employment effects can be derived. Employment is indicated in full-time equivalents (FTE).[3]

In the study, an analysis of gross effects was carried out, which means that the activities in Rüsdorfer Kamp are considered "in isolation". The study did not analyse the net effects of the transformation activities in the region. For example, it was not taken into account that due to the investments in Rüsdorfer Kamp, investments are not made elsewhere (in other sectors or regions) and that this may have negative effects on value creation and employment for the affected sectors, respectively regions.

Various scenarios are examined for the sensitivity analysis. Assumptions regarding the degree of regionalisation of the individual activities in the transformation process are changed, as well as prices and cost factors.

30.3 Assumptions and General Conditions

For calculations at the regional level, it is essential to make assumptions regarding various aspects. Some of these assumptions may influence results more than others, depending on their importance for regional value added. For example, it has a much stronger influence on the value added if the operator of the electrolysers can be located in the region, since then he triggers regional effects to a much greater extent not only through local tax payments, but also through his permanently incurred expenses (from the printer cartridge to the insurance contract to the personnel). Some assumptions could be supported by literature references. Crucial assumptions that form the framework for the baseline scenario can be found in Table 30.1.

To analyse the regional economic effects, two different scenarios are compared: The "BAU" scenario represents a conventional heat supply. Combined heat and power units (CHP) and a boiler plant generate the heat. In contrast, the scenario "operating grid" depicts an alternative and renewable heating system. Only in periods in which „green" electricity to operate the heat pump is not available or the supply with elec-

3 A full-time equivalent (FTE) is a key figure for the comparable measurement of employment. When determining full-time equivalents, part-time employees are taken into account with their share of the working hours of a full-time employee (one part-time employee is 0.5 full-time employees).

Table 30.1: Assumptions (selection) for the baseline scenario.

assumptions	2022	2035	2050	source
heat price	165.9 €/MWh	142.6 €/kg	121.8 €/kg	SIZ energy concept
hydrogen price	146 €/MWh	197 €/MWh	265 €/MWh	SIZ energy concept
debt ratio		50%		own assumption
margin		3%		own assumption
non-specific operating costs	0.2% – 1.5% from investment costs			own assumption
degree of regionalisation operator	100% regional			own assumption
degree of regionalisation installation companies	Depending on technology 10% – 90% regional			own assumption
regional share of non–specific[4] operating costs	50% to 90%			own assumption

tricity is interrupted e.g. by a technical defect, a CHP unit or a boiler plant is used.The electrolyser is used for sector coupling and the solar modules on the residents' roofs supply the large–scale heat pump with electricity. The core element is the operating grid. Table 30.2 shows selected features that distinguish the two scenarios.

Table 30.2: "operating grid" and "BAU" characteristics.

	Operating grid	BAU
components	boiler plant CHP electrolysis heat pump operating grid PV	boiler plant CHP
installation costs (in mill. euros, until 2050)	12.6	3.9
operation costs (in mill. euros, until 2050)	28.4	26.8

4 Non-specific operating costs are expenses for insurance, legal and tax advice, miscellaneous.

Table 30.2 (continued)

	Operating grid	BAU
revenues (Heat, H2, in mill. euros, by 2050)	20.3	26.5
thermal energy sold (2050, MWh)	5450	5468
heat price (Ø, Euro / MWh)	142.6	198.4

Due to a higher number of different plants and components installed, respectively built in the operating grid scenario, the installation costs in this scenario are more than three times higher than in the BAU scenario. The same applies to the operating costs, which is because part of the operating costs can be calculated as a share of the investment costs. Consequently, the difference in operating costs between the two scenarios should be higher. However, this is counteracted by the fact that the fuel costs (gas costs for CHP and boiler plant) as part of the operating costs in the BAU scenario (19 mill. euros) are around 10 mill. euros higher than in the operating grid scenario. The revenues from the sale of heat (26.5 mill. euros cumulatively by 2050) turn out to be about 6 mill. euros higher for the conventional than for the alternative heat supply, although the amount of heat sold is almost the same (5450 vs. 5468 MWh in 2050). This is due to the fact that heat prices are higher in the BAU scenario (Figure 30.1).

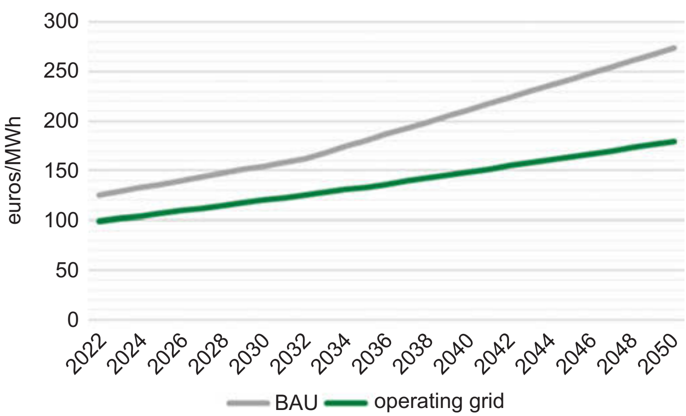

Figure 30.1: Heat prices in the scenario, (source: SIZ (2021), own illustration).

30.4 Regional Value Added

The installation of the components generates in the operating grid scenario a regional value added of around 4 mill. euros in the year of construction, while the activities in the BAU scenario triggers regional value added of around 1.9 mill. euros (Figure 30.2). Also throughout the period from 2022 to 2050, more regional value added is generated in the operating grid scenario (18 mill. euros) than in the BAU scenario (14.7 mill. euros). The regional value added during operating the plants/components differs in both scenarios only marginally: it is slightly higher in the operating grid scenario. Given the fact that Figure 30.2 shows cumulated figures, it becomes clear that the average value added effect on a yearly basis amounts to under one mill. euros by 2050. Thus, the majority of the difference in value added is attributable to the installation of the plants and the operating grid.

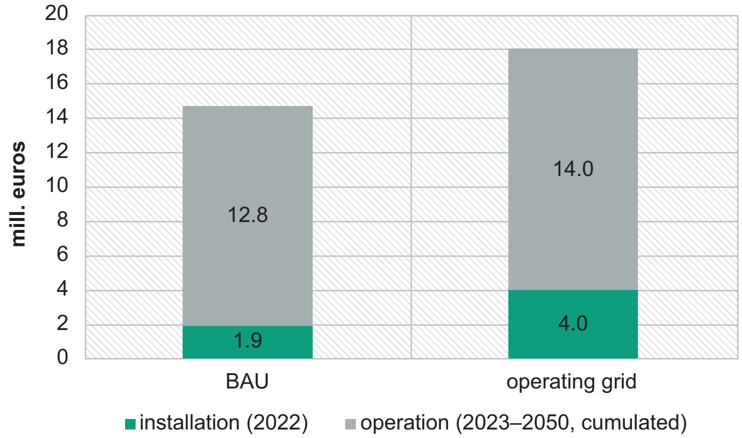

Figure 30.2: Regional value added in the scenarios, installation and operation by 2050.

In both scenarios, approx. 40% of the effects arise from activities directly linked to the transformation of the heating grid (e.g. installation of plants).

Activities, which are only linked indirectly to the work in Heide, are as well responsible for approx. 40% of the regional value added. These are effects resulting from the demand for intermediate inputs and services by companies in the same or a different economic sector and describe the effects that arise at upstream stages of the value chain (e.g. tax consulting, insurance). Additional value added in the region leads to an expenditure of the additional income and thus leads to a further positive effect on regional value added. These effects can be described as induced effects and account for approx. 20% of regional value added.

However, there are differences between the two scenarios with regard to the composition of the direct and indirect effects. In the operating grid scenario, about

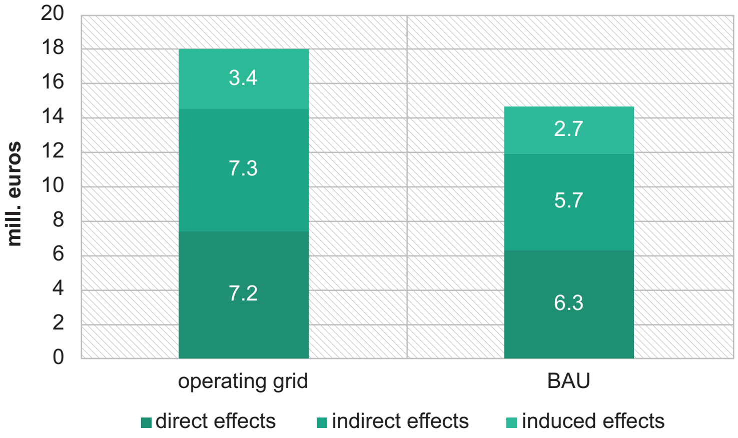

Figure 30.3: Composition of value added, scenarios, cumulated, 2022–2050.

43% of the regional value added effects are based on the regionally remaining **interest payments**. In the BAU scenario on the other hand, interest payments account for only 16% (Figure 30.3). In both scenarios it is assumed that around 50% of the installation costs are financed by borrowed capital and that annuity payments remain completely in the region. Due to the significantly higher installation costs in the operating grid scenario (12.7 mill. euros vs. 3.9 mill. euros), the annuity payments are correspondingly higher.

In the BAU scenario, on the other hand, regional **profits** contribute almost 60% to the total direct regional value added effects, which is approx. 3.7 mill. euros. In the scenario operating grid, the proportion of regional profits is only around 26%, at around 1.9 mill. euros. The reason why the remaining regional profit in the BAU scenario is almost twice as high as in the operating grid scenario can be found in the underlying heat prices shown in Figure 30.1. Although only heat is sold in the BAU scenario in comparison to the operating grid scenario in which hydrogen is sold additionally, higher heat prices in the BAU scenario lead to higher profits.

In terms of indirect value added effects, there is also a different weighting of the components the indirect effects are made up of: indirect income, material und income taxes (Figure 30.5). "Indirect" incomes are incomes that are paid on upstream stages of the value chain (insurance, tax accounting a. o.). In the operating grid scenario the regional remaining indirect income is responsible for approx. 66% of the indirect value added effects (4.9 mill. euros). In the BAU scenario, however, the main component is the indirect value added triggered by the material costs (3.2 mill. euros).

The level of value added effects depends basically on the costs. More cost–intensive activities generally also lead to higher value added effects. Figure 30.7 shows the regional value added generated per euro invested in each component in the two scenarios.

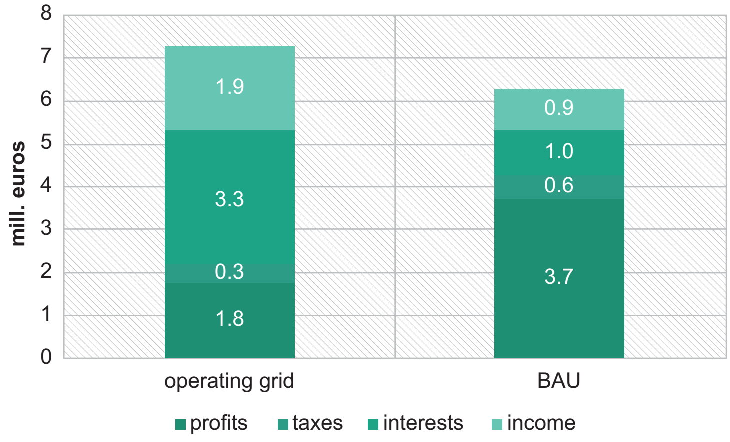

Figure 30.4: Composition of direct value added effects, cumulated, 2022–2050.

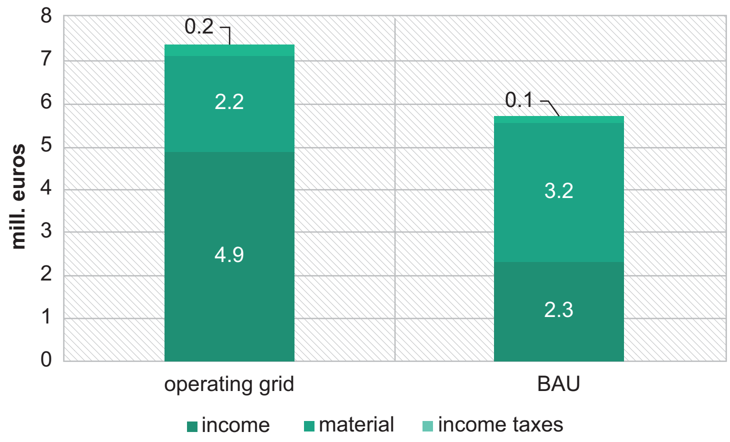

Figure 30.5: Composition of indirect value added effects, cumulated, 2022–2050.

In the operating grid scenario, the boiler plant and heat pump make the largest contribution to regional value added when costs are taken into account (0.86 euros per euro invested). Consequently the latter generates the most regional value added not only in absolute (Figure 30.6) but also in relative terms. The investment of one euro in electrolysis or CHP generates only 0.41 euros and 0.44 euros regional value added. Thus, these components are only half as "lucrative" as the heat pump.

In the BAU scenario, the boiler plant dominates when analysing the regional value added per euro invested (0.79 euros), whereas installation and operation of CHP only leads to 0.36 euros per euro invested.

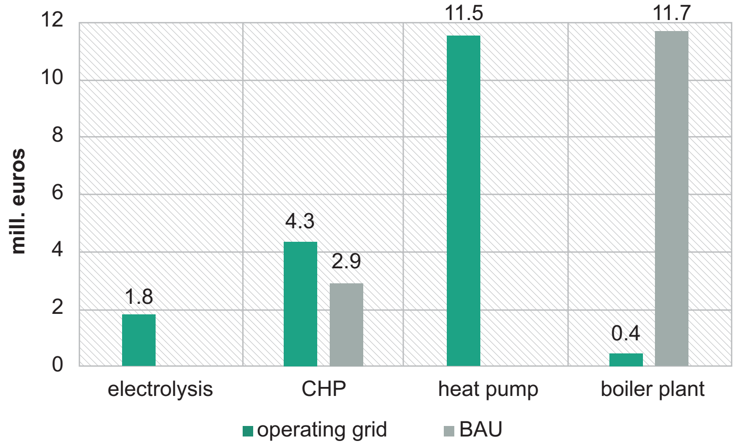

Figure 30.6: Regional value added by components, cumulated, 2022–2050.

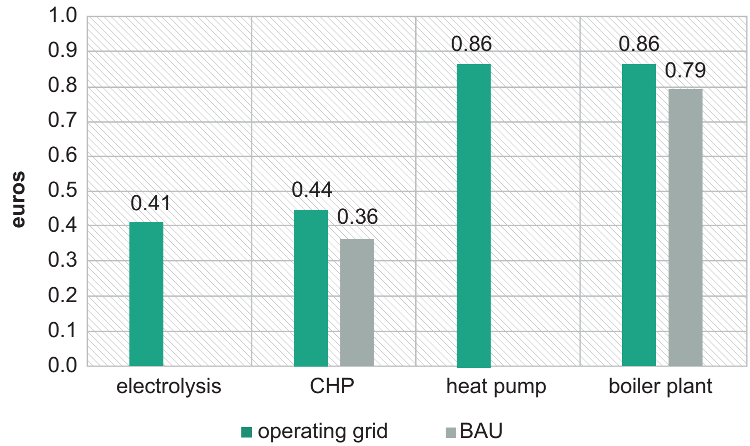

Figure 30.7: Regional value added per euro invested, by component, average, 2022–2050.

The effects on value added are concentrated in a few economic sectors. The construction industry benefits in particular in the areas of civil engineering and construction installations. Effects can also be observed in trade, as well as in the service sector (insurance, legal and tax advice).

30.5 Regional Employment

The work on the transformation of the energy system requires approx. 54 employees in the scenario operating grid and approx. 24 in the scenario BAU in FTE cumulated until 2050 (Figure 30.8). The labour requirement is almost entirely limited to the year of the installation of plants and components. It is assumed to take place in 2022. Replacement installations are assumed to take place at the end of the operating life of the respective plants / components. An increase in the demand for labour, however, does not mean that new jobs are created necessarily. It might be possible that workers work overtime for a limited period or labour may be reassigned from other projects. Over the entire period, the labour demand is largest for the installation of the heat pumps in the scenario operating grid (41 FTE). In terms of regional employment effects, the CHP plant (9 FTE), electrolysis and boiler plant (2 FTE) are far behind. In the BAU scenario, 20 workers are needed by 2050 to install the boiler plants and four workers to install the CHP plant.

In both scenarios, the indirect employment effects are significantly lower than direct employment effects. This is because only a small section of the value chain is considered. The calculation results provide information on how many employees are needed to carry out the activities indirectly related to the installation and operation of the plants or components. This includes, for example, employees in legal and tax consulting or in the insurance industry.

Figure 30.9 provides an overview of the indirect employment effects triggered by the activities in Rüsdorfer Kamp. On average, the activities employ around one person in the operating grid scenario and around 0.6 workers in the BAU scenario (in FTE).

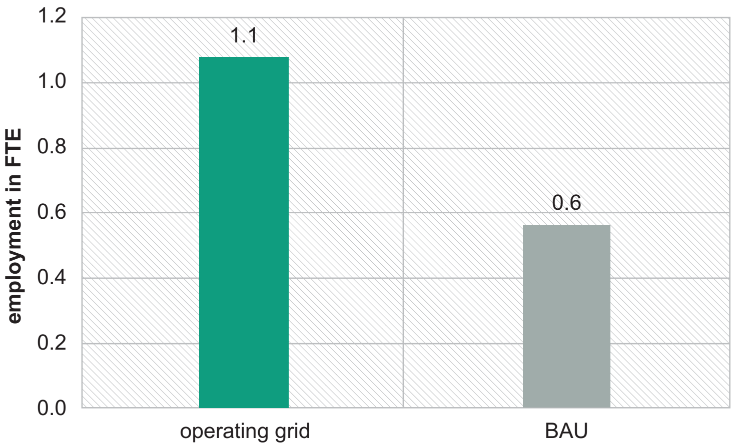

Figure 30.8: Direct employment of the components, scenarios, cumulated, 2022–2050.

30.6 Sensitivity Analysis

To gain insight into how the results change when selected input parameters are changed, the following sensitivity calculations were undertaken:

a. The non-specific operating costs (costs for administration, legal and tax advice, insurance and miscellaneous) were increased from between 0.5 and 1.5% of the investment costs in the operating grid scenario to 3% ("non-specific operating costs" scenario).
b. Change in the degree of regionalisation of the plant operators. Previously it was assumed that 100% of the plant operators were located in the region. This share was reduced to 50% ("regio" scenario).

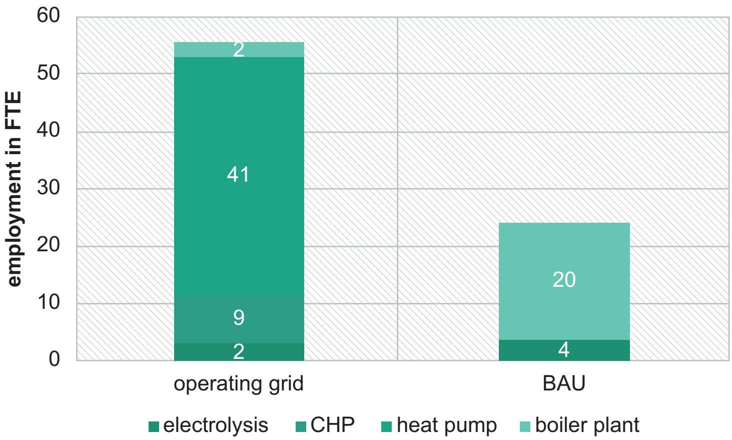

Figure 30.9: Indirect employment in the scenarios, average, 2022–2050.

30.6.1 Increase in Non-Specific Operating Costs

The increase in non-specific operating costs results in more regional value added being generated although costs increase. Whereas in operating grid scenario the cumulative regional value added is around 18 mill. euros by the end of the period (Figure 30.2), the regional value added effects in the non-specific operating costs scenario are more than twice as high at around 37 mill. euros (Figure 30.10).

The main reason for the positive effect on regional value added despite rising operating costs is that in the operating grid scenario, which forms the basis of the non-specific operating costs scenario, hardly any profits remain in the region. These amount to around 3.8 mill. euros by 2050. Higher costs lead to the fact that the profit in the scenario unspecific operating costs and thus the regionally remaining taxes are zero. However, this effect is more than compensated by higher regional remaining income. This follows the logic behind the calculation: the higher the turnover (assumption turnover = costs in our calculations), the more personnel are needed and consequently the higher the income.

Figure 30.11 shows the composition of regional value added in the two scenarios.

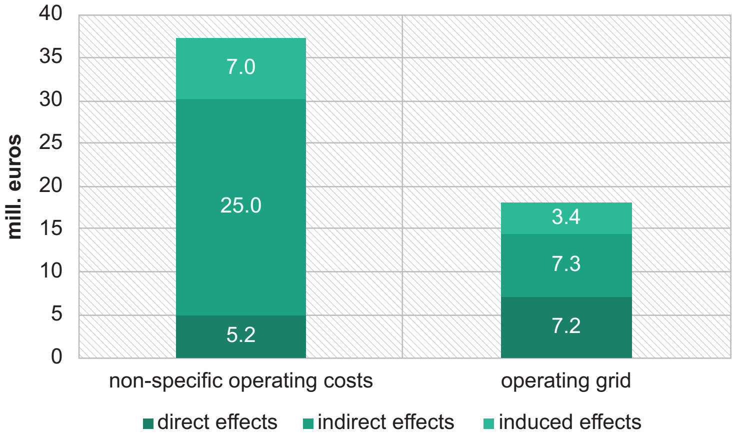

Figure 30.10: Regional value added, scenarios, cumulated, 2022–2050.

As shown, higher non-specific operating costs lead to higher regional value added. However, when considering the regional value added in relation to the euro invested, the result of the operating grid scenario is more positive. In this scenario, an average of around 0.64 euros of regional value added is generated per euro invested throughout the period. In the non–specific operating costs scenario, the generated regional value added is 3 cents lower at 0.61 per euro invested. As shown in Figure 30.12 the investments in the heat pump and in the boiler system are more "lucrative" in the in the operating grid scenario at 0.86 euros each than in the non–specific operating costs scenario at 0.65 and 0.74 euros of regional value added per euro invested. The opposite is true for the electrolysis and CHP

While direct employment is the same in both scenarios, annual average indirect employment in the non–specific operating costs scenario is more than three times higher at 3.7 persons (FTE) than in the operating grid scenario at around one person (FTE) (Figure 30.13). This is due to the fact that according to the calculation method indirect employment can be derived by non–specific operating costs, thus the higher the costs, the more labor is assumed to be needed. Higher unspecific operating costs, however, do not influence investments costs and therefore do not create additional demand for employment.

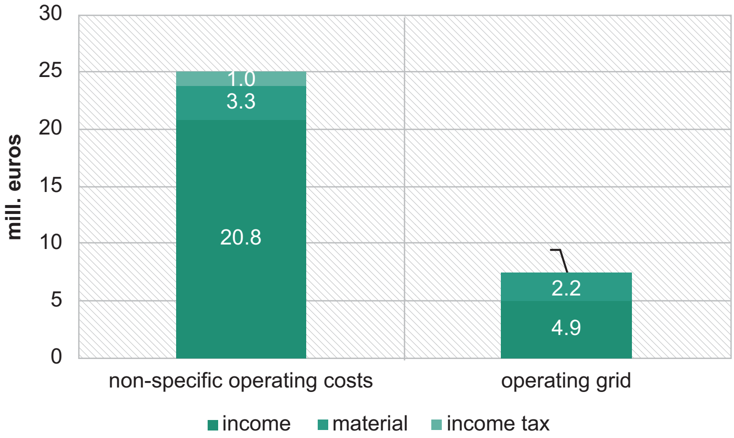

Figure 30.11: Composition of indirect value added, scenarios, cumulated, 2022–2050.

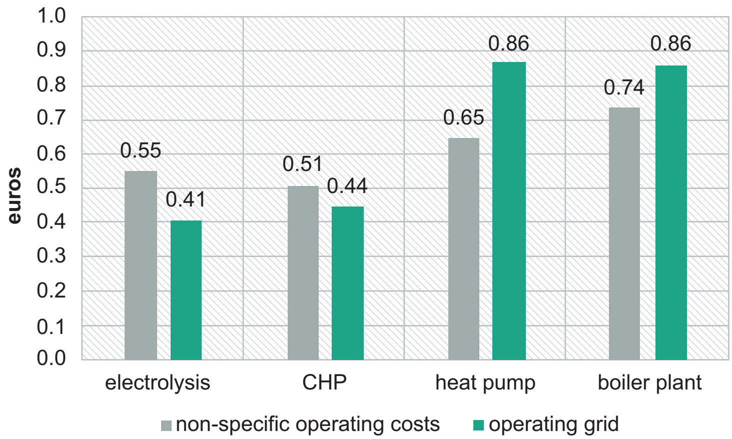

Figure 30.12: Regional value added per euro invested, scenarios, cumulated, 2022–2050.

30.6.2 Reduction in the Degree of Regionalisation of Plant Operators

In the operating grid scenario, it is assumed that 100% of the revenues from the sale of heat remain in the region. In the sensitivity calculation (regio scenario), however, it is assumed that the degree of regionalisation of the plant operators is reduced to 50%. This means that only about half of the revenue from heat sales remains in the region. Figure 30.14 shows the effects on regional value added.

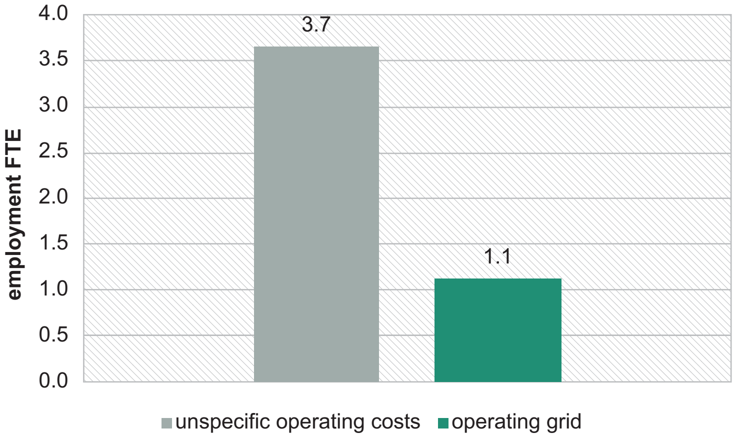

Figure 30.13: Indirect regional employment, scenarios, annual average, 2022–2050.

Overall, the regional value added in the regio scenario of around 16.5 mill. euros is around 1.4 mill. euros lower than in the operating grid scenario. The indirect regional value added effects are almost the same. This is because the amount of revenue only has an influence on the remaining regional profit and thus on the direct effects. Since the induced effects can be derived from the direct and indirect effects, the induced effects are also lower.

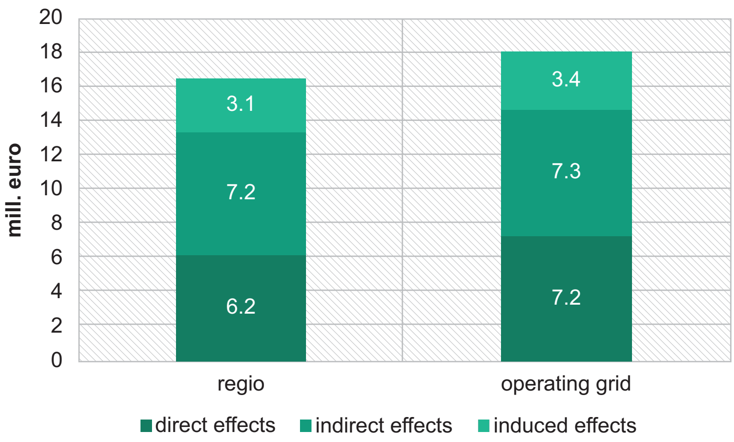

Figure 30.14: Regional value added by composition, scenarios, cumulated, 2022–2050.

Figure 30.15 illustrates that the reduction in the degree of regionalisation of the system operators only affects the regional value added of the heat pump. This can be explained by the fact that this is the only component for which profits remain in the region. In all

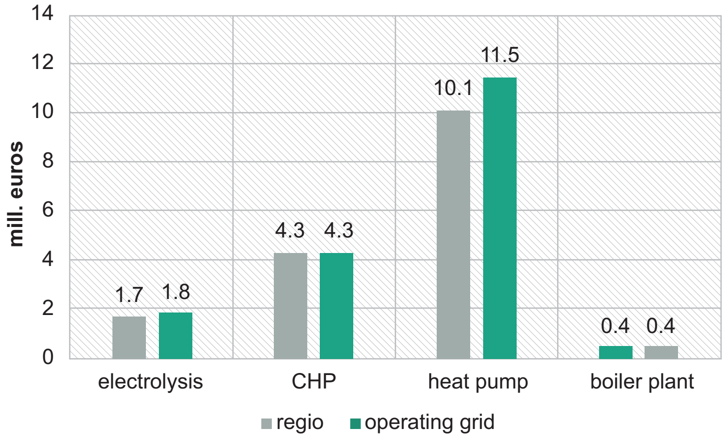

Figure 30.15: Regional value added by component, scenarios, cumulated, 2022–2050.

other cases profits and therefore local tax payments are zero. These profits, which result from the regional remaining margin and the revenues from heat and hydrogen sales (electrolysis) minus the total operating costs, only accrue for the heat pump. This means that a "decline" in the regionally remaining revenues also only has an impact here. Effects on employment are not observed because the cost components from which employment effects are derived are not affected.

30.7 Summary

The redesign of the heat supply of the Rüsdorfer Kamp neighbourhood in the city of Heide leads on the one hand to a future-oriented development of the neighbourhood in terms of energy supply through the implementation of an electrolyser, a heat pump (in addition to a CHP and a boiler plant) and an operating grid. On the other hand also to positive regional value added and employment effects. The actions to transform the neighbourhood's energy system generate a regional value added of about 17.9 mill. euros over the entire period against the background of the assumptions made regarding, for example, the regionality of various activities. The transformation based on a conventional heat supply with CHP and boiler plants generates about 5 mill. euros less in regional value added. In general, the more cost-intensive a component is, the more value added it generates. To gain an insight into how "lucrative" the individual components are in terms of value added, the ratio of regional value added to the euros invested per component was examined. The ratio is particularly positive for the heat pump and the boiler plant, which generate around 0.86 euros of regional value added per euro invested (operating grid), while the latter generates 0.79 euros in the BAU scenario. Installation and operation of the electrolyser in the Rüsdorfer Kamp only generate 0.41 euros per euro invested.

For the sensitivity analysis, first, the non-specific operating costs i.e. costs for insurance services, legal and tax advice, administration and miscellaneous were increased from between 0.5 and 1.5% of investment costs to 3% of investment costs. Second, the degree of regionalisation of plant operators was reduced. While in the operating grid scenario it is assumed that the operators can be located 100% in the region, in the sensitivity calculation it is only 50%. The effect of a reduction in the degree of regionalisation only leads to 1.4 mill. euros less regional value added throughout the period, while the effect of the increase in non-specific operating costs is significantly higher. It leads to a doubling of the regional value added (around 36 mill. vs. around 18 mill. in the operating grid scenario).

For transformation activities in Rüsdorfer Kamp about 54 employees (in FTE) are needed by 2050 in the operating grid scenario. In the BAU scenario only 24 employees are required. By far the most employees are required in the installation of the heat pump. During the operating period, an average of about one employee (FTE) is required annually in the operating grid scenario and about one FTE (0.6) in the BAU scenario. When changing parameters to perform sensitivity analyses, only changes in non-specific operating costs affect employment and thereby only indirect employment. In this scenario, the average annual demand during the operating phase increases from one FTE to about 3.5 FTE. The reason for the omitted effects in the other sensitivity calculation is that the reduction in the degree of regionalisation of the plant operators has a direct impact on the regional remaining profit. However, since profits only occur in the case of the heat pump, the effect thus “fizzles out”.

Further investigations and applications of the developed tool are conceivable. For example unplanned external effects (e. g. gas price shock) could be integrated into the model.

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Jürgen Görres, Simeon Kühl, Melissa Siegl, Heike Erhorn-Kluttig, Katrin Lenz, Henner Gimpel, Valerie Graf-Drasch, Annette Roser, Karin Schakib-Ekbatan, Anneka Ressel

31 Presenting the lighthouse of energy transition „STADTQUARTIER 2050“

Summary: The state capital Stuttgart and the large district city Überlingen on Lake Constance are working together with eleven other partners on the lighthouse project "STADTQUARTIER 2050" on converting two urban residential districts in a socially responsible, climate-neutral way and transferring the concepts to other quarters. In addition to the demonstration districts, the project partners are working on technological issues, on the socio-scientific accompaniment of the implementation and are developing four different tools for application in city districts.

31.1 Introduction

The cities Stuttgart and Überlingen are working together on the project "STADTQUARTIER 2050" to achieve the common goal of a climate-neutral energy supply, which is to be achieved at the federal and state level by 2045 and 2040. In 2018, the city of Überlingen decided to reduce its greenhouse gas emissions by 80–95% by 2050 as part of the climate protection master plan. (Energieagentur Bodenseekreis 2018) Back in 2016, the state capital Stuttgart set itself the goal of "climate neutrality by 2050" through a resolution of the Stuttgart City Council (Stuttgart 2016) in order to manage without nuclear power and coal in the future. It is currently examining which measures it can take to become a climate-neutral state capital by 2035. The ongoing discussion about tightening the federal and statewide targets through suitable measures shows the importance of the project and the relevance of appropriate solutions.

In the project, the two cities are working together with research institutes (the Fraunhofer Institutes for Building Physics IBP and for Applied Information Technology FIT, the Institute for Resource Efficiency and Energy Strategies IREES, the Institute of Construction Materials IWB at the University of Stuttgart and the Research Institute

Jürgen Görres, Simeon Kühl, state capital Stuttgart
Melissa Siegl, city Überlingen
Heike Erhorn-Kluttig, Katrin Lenz, Fraunhofer IBP
Henner Gimpel, Valerie Graf-Drasch, Fraunhofer FIT
Annette Roser, **Karin Schakib-Ekbatan,** IREES
Anneka Ressel, Baugenossenschaft Überlingen eG

https://doi.org/10.1515/9783110777567-031

for Thermal Insulation FIW) as well as practice partners such as Stadtwerke Stuttgart, Stadtwerk am See, Baugenossenschaft Überlingen, puren GmbH, Energieagentur Ravensburg and associated partners Stuttgarter Wohnungs- und Städtebaugesellschaft and Saint-Gobain.

As part of the project, over 960 residential units are being built with a total investment of around 190 million euros. In Stuttgart, the project involves the conversion of a former hospital with redevelopment, partial demolition and new construction. In Überlingen, the project consists of the redevelopment of a peripheral area as well as the construction of new buildings on the outskirts of the city. Since both cities have similar tasks ahead of themselves, but in different districts, the systematic project approach enables the transfer of results and experiences from the demonstration districts within the respective city and to other municipalities.

Both demonstration districts aim to design, plan and implement a climate-neutral energy supply for the buildings – in terms of heat and electricity, including user electricity – and thus to reduce the dependence on rising energy prices. The evaluation parameter are the equivalent CO_2 emissions in the annual balance. An evaluation of the grey energy is planned as part of the life cycle assessment (LCA). In the process, various boundary conditions must be taken into account in the districts, such as the different structure of ownership with existing homeowner associations, or the aim of combining a high percentage of social housing with a climate-neutral energy supply.

A building energy standard up to “KfW Efficiency House 40 Plus” will be realised in the districts. The infrastructure solution sets include a cold local heating network and the use of local renewable energies for both heat and electricity, i.e. solar thermal energy, photovoltaics on roofs and facades, geo-thermal energy, wastewater heat and biomass. Through thermal and electrical storage systems, which are used both centrally and decentrally, and the integration of e-mobility, a sector coupling occurs, which increases the share of energy used on site and thus relieves the upstream grid. To prove that the goal of a quarter with a climate-neutral energy supply can be achieved in practice, appropriate monitoring is planned. Concepts are being developed and implemented to track energy consumption in the district and to analyse the technologies and their combination in detail.

The socio-scientific work focuses on the motivation of the residents of the homeowner associations to participate in the renovation, on socially acceptable renovation and on the development of a bonus system tailored to the users, which is intended to ensure conscious energy consumption. The various residents will be interviewed and their wishes and requirements for a climate-neutral district will be recorded in order to subsequently evaluate the technologies used in terms of resilience and user-friendliness.

Accurate electricity and heat demand data of residential districts serve as input values for the calculation of optimised quarter networks. Furthermore, different approaches for greenhouse gas neutrality of quarters as well as their economic and life cycle assessment (chapter 31.3.4) are considered. The theoretical considerations are put into practice with the tools “GridOptimizer” (chapter 31.5.3) and “Klimaneutral

Easy” (chapter 31.5.2). Rebound effects are reduced by informing tenants, whereby the quarter app (chapter 31.5.1) combines information for residents, specific recommendations for action, gamification and a bonus system (chapter 31.4.3). All the tools developed in the project are being tested in the districts and municipal offices and should be transferable to other districts and cities, just like the scientific results.

31.2 Climate-Neutral Supply of Residential Areas – Common Features of Two Different Quarters

Across Germany, many cities are currently facing the challenge of having to drastically reduce greenhouse gas emissions in the building sector. In this context, it is helpful to consider not the individual building, but several buildings in a network, as jointly used generators and local heating solutions have economic and climate-relevant advantages. In addition, district services such as cafés, car sharing and shared open spaces increase the attractiveness of the district.

To implement the planned projects, the cities of Stuttgart and Überlingen have joined forces with two different quarters. In Stuttgart, the focus is on the conversion of a centralformer hospital, which includes the refurbishment of several buildings and large-scale new construction, while in Überlingen, on the outskirts of the city, new buildings are being constructed and existing ones refurbished in several construction phases.

In addition to the issues of climate change, the two cities also face similar challenges regarding other topics, such as affordable housing, a liveable, cool and congestion-free city, as well as the danger – not only posed by the Corona pandemic – of inner cities becoming deserted. These issues are discussed in an exchange between the two cities, called “the Cities Platform”. In regular meetings, the representatives of the cities exchange ideas about the targeted quarter concepts, technical measures, experiences already made, obstacles and their solutions as well as communication measures. The transfer of results to other districts and cities is of great interest and was planned from the beginning, so that this exchange cross-fertilises both quarters from the start and directs them towards achieving the goals pursued by the project.

31.2.1 The Quarter Bürgerhospital in Stuttgart

The quarter is located on the former hospital grounds of the Bürgerhospital and is charac-terised by an open construction. This will be extended by a perimeter block development, while keeping the former patient garden, the main ward building and two remaining buildings from the constructon period of the Bürgerhospital in 1894.

The intention is to create an urban quarter with at least 600 flats and a forward-looking approach, socially mixed, with day-care centres, a district house and a grocery shop, in which green spaces such as the former patient garden with its old trees contribute to a high livability. This offers the opportunity to design the area as a neighbourhood with the municipal housing company Stuttgarter Wohnungs- und Städtebaugesellschaft and other honeowner associations.

Based on the results of first studies, location requirements for the district were discussed with the public from 2016 onwards. The subsequent urban planning competition was won by architects Pesch & Partner (see Figure 31.1). Based on this, the first buildings were renovated and an architectural competition was held for the first new construction phase, the results of which will be implemented in the coming years.

Figure 31.1: Visualisation of the winning design by Pesch & Partner, demonstration district in Stuttgart. © ArchitekturbÜro pesch partner architekten stadtplaner GmbH (2017).

The energy concept pursues the goal of a climate-neutral electricity and heat supply for the area. This also includes user electricity. To achieve this goal, the energy demand of the quarter is minimised through high building standards for new buildings and renovations. The remaining energy demand is covered by an energy supply with the highest possible proportion of locally generated, climate-neutral heat and electricity. The quarter app developed in the project also encourages residents to save energy.

The planned energy supply (see Figure 31.2) is structured as follows:

– The heat supply for the quarter is provided by an intelligent coupling of renewable sources such as geothermal energy, wastewater heat and solar heat by

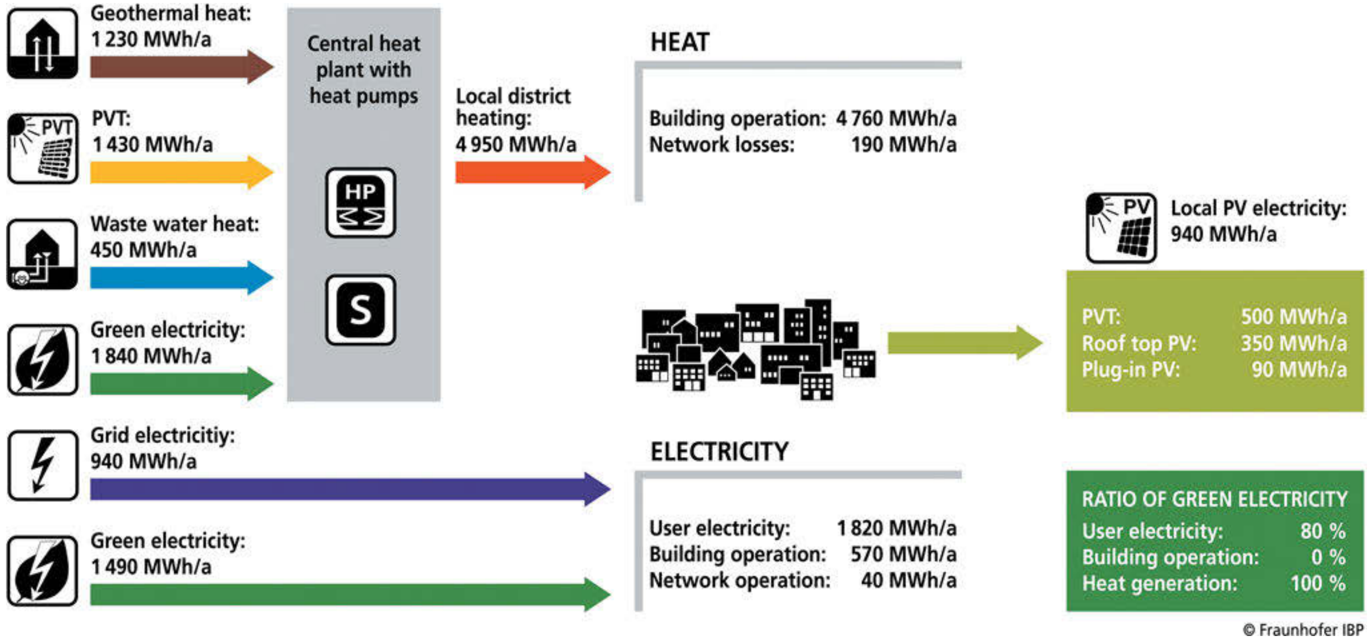

Figure 31.2: Energy flow diagram of the favoured energy concept for the climate-neutral energy supply of the quarter Bürgerhospital in Stuttgart, (source: Fraunhofer IBP (2021)).

means of a district heating network including a storage tank. The use of district heating is being examined as redundancy or to cover peak loads.
- By covering as many roof and facade surfaces as possible with photovoltaic modules, a high percentage of the electricity required in the quarter is to be generated.

So far, an analysis of the existing geothermal and wastewater heat potentials and a rough dimensioning of the systems engineering including a cost estimate and profitability analysis were prepared. In addition, the local district heating unit for the interim and final supply were built and the selection of location for the heat storage tank was advanced.

The development of the district will take place in several construction stages until the mid 2030s. This requires a progressive implementation of the energy concept and an interim solution for the heat supply of the buildings currently still in use. Attention was paid to ensure that the infrastructure (e.g. the local district heating unit) can be retained as far as possible for the final supply.

The former ward building of the hospital is being renovated and converted into a residential building with 130 units. In the autumn of 2023, the first tenants will move in. It is estimated, that this building will have a high share of approximately 30% of the total energy consumption of the area, which leads to the fact that energy saving measures that are planned here will have a great impact on the climate neutrality of the entire quarter. The optimisation measures, which were coordinated with the Stuttgarter Wohnungs- und Städtebaugesellschaft as the building owner, include underfloor heating in the flats in addition to fresh water stations for each flat.

31.2.2 The Quarter Hildegardring/Schättlisberg in Überlingen

The plan is to expand the existing quarter Q5-Hildegardring of the building cooperative “Baugenossenschaft Überlingen” by 180 new flats in a cooperative context for affordable living. The new buildings are designed according to the KfW Efficiency House Standard 40 Plus. Planned arehighly efficient low-tech buildings that are particularly resource-friendly in construction and energy-efficient, rugged and durable in operation. Not least because of the use of innovative and recyclable high-performance thermal insulation materials from one of the local project partners, the operating costs can be kept permanently at a very low level. The first two construction stages with 130 flats have been completed, connected to the local heating network and occupied (see Figure 31.3).

A special feature of the heat supply to the district is the innovative connection to the local heating network of the Stadtwerk am See, a public utility company, through an innovative 3-pipe network. Thus, synergistic effects for a more efficient heating network can be achieved through the joint integration of existing and new

Figure 31.3: The demonstration district in Überlingen, (source: Baugenossenschaft Überlingen (2021)).

buildings. The adjacent quarter Hildegardring from the 1970s will be upgraded to KfW standard 55.

The new 3-pipe network in the district is intended to further reduce the return temperatures of the heating network to the generation plants in order to reduce network losses. For this purpose, the return flow of the existing quarter is used as a “warm” flow for the new quarter. This is sufficient for heating by means of panel heating. For the preparation of drinking water and as a redundant supply – if the amount of energy from the “warm” flow is too low – the regular hot flow is used. The decreased temperature of the return flow improves the efficiency of the existing power station. Furthermore, solar heat as heat source can make a greater contribution to heat generation. Lower temperatures increase the lifespan of the solar heating system on the one hand and the efficiency of the system on the other.

The heat for the quarter is generated by solar heat, woodchips and a combined heat and power plant. A large buffer storage is also installed for better balancing of generation and demand. In this way, the term of the additional gas boiler for peak or emergency supply can be significantly reduced. The wood is to be obtained exclusively from the nearby forests of the Überlingen hospital and donation fund. This way, complete added value can be achieved locally with a high degree of sustainability. By using electrostatic precipitators, this central solution can also significantly reduce the particulate matter output compared to individual wood-fired furnaces and small wood-fired central heating systems.

In terms of electricity generation, attention is also paid to a high level of self-sufficiency. Photovoltaic systems are installed or planned on all new buildings. The temporal offset of electricity generation and demand is compensated by battery storage in order to use a higher percentage of the generated electricity on site. Exceeding the support framework, the residents are offered the opportunity to use the electricity generated locally on the roof with a landlord-to-tenant model and thus participate directly in the local renewable energy supply.

31.3 Technological Issues

In addition to the work in the demonstration districts, several technological issues are being addressed in the project. Electricity and heat demand data from residential districts are compiled and serve as input for the calculation of optimised district grids and the tool "Grid Optimizer". Possible solutions for the CO_2 neutrality of quarters are analysed and their economic and ecological effects are evaluated.

31.3.1 Determination of Fine-Granular Electricity and Heat Demand Data

As part of the project, the energy consumption of the residential districts is to be mapped as accurately as possible to manage the energy supply smartly and digitally by the tools developed in this project. In order to realise this in the best possible way, a database containing fine grained data on the power and heat demand of the district residents is necessary.

One of the distinguishing features of the quarters is that they not only consume energy, but also generate it. The consumption of the districts should be, to the greatest possible extent, covered by self-generation. In order to synchronise consumption and generation as much as possible, firstly it is necessary to have precise knowledge of electricity and heat demand data. The user profiles of the residents with regard to electric power consumption are particularly important. For this purpose, fine-granular consumption data of different energy sources (electricity, heat, hot water) can be combined with knowledge about building physics (e.g. insulation), indoor climatic (e.g. room temperature, humidity), outdoor climatic (e.g. solar radiation, outdoor temperature, precipitation) and household- related parameters (e.g. age, occupation, energy use behaviour). Because these data are not yet available from the project, an external dataset was chosen. It became clear that the Irish dataset from ISSDA (ISSDA 2020) best meets the requirements needed for the project in terms of the width and information content.

As part of the project, an overview of relevant use cases of the electricity and heat demand data was developed, as well as a data protection and data security concept. Energy demand profiles for the residents of the districts were derived from the ISSDA data set. These were divided into six clusters:

1. Extended families
2. Married couples of older age
3. Singles and couples

4. Families with children (parents 36 to 45 years)
5. Families with children (parents 46 to 55 years)
6. Low-income families

Based on the data from these clusters, estimates of the expected power requirement curves over the course of the year were created using sample data from a comparable district in Stuttgart or the flats already occupied in Überlingen. In the next step, recommended actions were derived for the various target groups. For example, one recommendation is to shift electric power consumption from the evening to the afternoon, as the share of photovoltaic electricity is significantly higher here. Electricity suppliers are advised to provide incentives to use more renewable electricity with a flexible electricity tariff.

31.3.2 Solution Sets for a Climate-Neutral Energy Supply for Quarters

In addition to the two concrete plans and the implementation of climate-neutral quarters in Stuttgart and Überlingen, general solution sets for the climate-neutral energy supply of residential districts were compiled and evaluated for different types of residential quarters. The results of the work are published in a guideline and form the basis for the tool “Klimaneutral Easy”. The guide and the tool will be accessible via the project homepage. (Fraunhofer Gesellschaft 2019)

As described in more detail in the book chapter 32 “Solutions for climate-neutral district concepts”, five different types of housing settlements according to Neuffer/Witterhold/Pfaffenberger et al. (2001) were mapped using type buildings from the building catalogue of the institute “Institut für Wohnen und Umwelt” (Loga/Stein/Diefenbach et al. 2015). They were then evaluated in terms of energy for the combinations of four energy-related building levels, twelve decentralized and eleven centralized supply concepts as well as three climate zones using the calculation method of DIN V 18599 (Beuth-Verlag 2018). In addition to the final energy demand and greenhouse gas emissions, the investment costs, the energy costs and the remaining compensation costs for achieving climate neutrality were determined. The resulting evaluation matrix shows the perspectives of the investor (investment costs), the resident (energy costs), the municipalities (remaining compensation costs) and a macro-economic consideration.

In addition, other influencing factors were evaluated, whether in favour or against an energy concept. These include future viability, expandability, robustness and grid efficiency. Filtering questions such as the existence of a district heating network, existing open spaces or the possible use of groundwater as a heat source can be used to eliminate unsuitable supply types.

31.3.3 Evaluation of the Economic Efficiency of the Energy Concepts for Transfer to other Future Urban Quarters

In times where, on the one hand, more affordable housing is demanded and, on the other hand, high investments in energy efficiency measures are necessary to achieve climate neutrality, the question arises whether these two demands can be conciliated. Therefore, the economic efficiency of the districts must be assessed for the stakeholders involved. For example, it is of interest to tenants to achieve savings through reduced energy consumption at a slightly higher rent. For investors, on the other hand, the return on investment is the primary point of interest. This evaluation dimension is complemented by the associated uncertainties (e.g. energy price or climate changes), which are relevant for investments in energy efficiency measures. Based on the energy concepts of the two districts, an exemplary economic efficiency evaluation was performed.

The net present value method was identified as a suitable method for profitability analysis due to its widespread use in literature and practice as a dynamic investment evaluation method. The advantage is the consideration of opportunities and the robustness against uncertainties. With the help of a Monte Carlo Simulation, the future energy costs were modelled as a variable on the basis of the energy price development from 2005 to 2019. In this way, both the expected net present value and a risk ratio can be determined. The economic evaluation thus provides information on whether it is economically profitable to invest in climate neutrality according to the expected value and how the economic efficiency behaves in the event of an unfavourable development of energy prices.

In addition to the procedure described above, the effects of a CO_2 price are included in the economic efficiency evaluation. This happens against the background of the latest development of climate policy in Germany, but also because the city of Stuttgart bases its internal profitability calculations on a CO_2 price of 50 €/t in 2020 (with an annual increase of 15 €/t).

The energy supply concepts planned in the two demonstration districts were compared and evaluated with two individual reference concepts (for Stuttgart and Überlingen). In addition to the net present values, in connection with the investor and tenant perspective, a rent including heating costs based on the energy concepts was calculated. It is defined in such a way that it does not place an additional burden on the tenants, as higher rental costs and lower energy costs balance each other out and lies at approximately one extra euro per square metre. In this way, the rent including heating costs combines the two project goals of “climate-neutral” and “affordable” housing.

31.3.4 Life Cycle Assessment

Life cycle assessment (LCA) studies are carried out to determine environmental potentials over the life cycle of the districts, such as the contribution to climate change or the use of non-renewable primary energy). They are intended to provide information on the additional share of construction-related emissions that are not included from the perspective of climate neutrality beyond the mere consideration of the district operation. On the other hand, the results are used to derive ecological potential for optimisation for construction-related aspects in the districts.

Based on the standards available in civil engineering (Beuth-Verlag 2012, 2020), specific life cycle assessments are implemented for the energy concepts from Stuttgart and Überlingen as well as for the solutions developed in the project for a climate-neutral energy supply at district level. Following elements arecomponents, which are part of the assessment framework:

- Production, maintenance, operation and End-of-Life for new constructed buildings and buildings with refurbishment measures;
- Operation of existing buildings or the existing building stock;
- Production, maintenance, operation and End-of-Life for energy supply concepts (technologies for energy supply as well as infrastructure for distribution and transfer and potential compensation measures (e.g. via photovoltaic).

The aim is to derive robust results both for the individual district elements and for the quarter as an overall starting point for optimisation with regard to climate neutrality. By identifying relevant interrelations, influencing variables and interactions, the results of the life cycle assessment support the stakeholders involved in the planning and implementation process and can address their specific questions.

A large part of the project focuses on the setup of specific life cycle assessment models for energy supply technologies with the help of the expert software “GaBi” (Sphera Solutions GmbH 2022). Models are being created for combined heat and power plants, heat pumps, geothermal energy, local heating networks, photovoltaics, wastewater heat recovery, solar heat, ventilation and cooling. The models for the building types used in the project (new/existing, residential/non-residential) are implemented using the Generis® building life cycle assessment software (GENERIS 2022) and environmental information on building products based on the publicly available database “ÖKOBAUDAT” (BMWSB 2021). The environmental information for the life cycle assessment is subsequently incorporated into the urban planning tool “District ECA” (District ECA 2022), which will be expanded by a life cycle assessment module (see chapter 31.5.4). In this way, the LCA results can be taken into account already within the early planning of energy supply concepts.

31.4 Social Science Support for Implementation

The social science work focuses on motivating the homeowner associations to participate in the district renovation and on developing a bonus system for more conscious energy use. Stakeholders are involved through information events, focus groups and written surveys.

31.4.1 Exemplary Coordination Process Regarding Buildings Worth Preserving

The ward building in the quarter of Stuttgart was classified as worthy of preservation. Detailed investigations are used to analyse and evaluate the building fabric in order to be able to provide information on elements worthy of monument protection. Accordingly, a catalogue of building components that will provide information typical of the building's age about the materials used and constructions found in the originally tiled building is being developed. The basis for the evaluation of the building consists of historical and constructional investigations as well as information on building physics and material science that were carried out on the building in a field survey.

At the same time, existing planning documents and supplementary available literature on the structure were researched. Among other things, the original plans could be viewed at the archive "Südwestdeutsches Archiv für Architektur und Ingenieurbau" in Karlsruhe. Samples were also taken from the building's outer surface components. In order to locate thermal bridges, identify special construction features and the tightness of the facade, it was analysed with an infrared camera and a number of other examination methods.

The material assays were subjected to detailed analyses in the laboratory in order to determine both physical and structural-mechanical material parameters that can be used to characterise the structural-physical behaviour of the materials used. The pore structure of the materials used in the facade components was determined. From the pore geometries and the distribution and frequency with which pores of a certain size are found in the material structure of the building materials, exact estimates of the thermal and moisture behaviour of the building materials can be derived. Meanwhile, hygrothermal simulations were implemented on the structural conditions of the outer envelope surface components. Furthermore, the U-values of the external facade were determined and the heat and moisture balance in the building components as well as in thermal bridge areas was estimated.

Further activities focus on the energy renovation of buildings with a tile facade similar to the one that was applied to several buildings in the quarter of Stuttgart. Based on this, a component catalogue will be compiled, which compares the advantages and disadvantages of an energy measure from the structural-physical, building constructional and ancient monuments preservational point of view. Moreover, concepts will be developed about how energetic improved efficiency of the original tiled facade could have been realised. The results of the project will be discussed with the authorities of preservation of ancient monuments in workshops in order to clarify the portability of the results to other listed buildings with tiled facades.

31.4.2 Motivation / Coordination of Housing Cooperatives and Homeowner Associations in Überlingen

In order to achieve the goal of a climate-neutral energy supply for the entire district in Überlingen, as many buildings as possible should be connected to the 3-pipe local heating network. In addition to the new buildings, which are integral parts of the concept, the focus is on the existing buildings that are not owned by the Baugenossenschaft Überlingen. Other housing co-operatives and homeowner associations own these buildings. For these buildings, options were considered with regard to measures on the building envelope and technology. These were discussed in detail in expert interviews and group interviews with board members and advisory board members of the homeowner associations in the quarter of Überlingen. Aditionally, possibilities for contributing to a climate-neutral energy supply, and thus to the energy transition, were identified that can also be transferred to other buildings of the housing cooperatives. Valuable information about building-specific conditions and the motivation of the residents could be gained. Overall, the goals of the project “STADTQUARTIER 2050” were received positively by the participants. The information and discussion on topics such as balcony photovoltaic systems, possibilities for individual measures for energy-efficient renovation and funding opportunities were rated as helpful. The results of the focus groups were seen as a good argumentation for the development of an overall strategy for energy-efficient refurbishment by the participants of the homeowner associations. They assessed it as a solid basis for reducing the expected concerns of other owners in the upcoming meetings.

31.4.3 Development of a Bonus System to Support Energy-Saving Behaviour

In addition to energy-efficient construction and a renewable energy supply, the behaviour of residents is a key factor in a climate-neutral quarter. Despite increasing awareness of environmental issues and problems, everyday activities often show discrepancies between growing environmental awareness and behaviour that is nevertheless harmful to the environment. (Gimpel/Graf/Graf-Drasch 2020) Examples are open windows while the heating is on or using electrical appliances unnecessarily. The reasons for this can be complex and include behavioural relevant attitudes, lack of knowledge or lack of competence. In the context of housing, there are many opportunities for energy-saving and environmentally friendly behaviour. Often, extensive educational work and efforts at persuasion are required to promote motivation for energy-saving behaviour. In this context, in addition to the development of the quarter app, the development of a suitable bonus system is also planned. This should encourage residents of the districts to participate in climate neutrality and energy efficiency goals and reward the successful achievement of these goals.

For this purpose, a portfolio of measures was created and three incentives were distinguished, each of which addresses different motives: hedonistic (linked to comfort), egoistic (linked to economic benefits) and altruistic (e.g. importance of one's own behaviour for society). In addition, an overview of relevant groups of people who could be considered as users of the bonus system in the two quarters was compiled. These were differentiated according to the following dimensions: energy efficiency behaviour, motivation type and social milieu. Further descriptive characteristics of groups of people are household size, age, occupational status. If one now links groups of people with the incentives mentioned, all groups of people can be effectively addressed.

A system of incentives for energy-saving behaviours tailored to different groups of people was developed. For this purpose, a total of fifteen intervention measures were identified within the framework of a comprehensive literature research and evaluation of practical examples and adapted to the context of "energy-efficient behaviour". For better clarity, the measures were assigned to different categories (convenience/salience, information provision, monitoring/feedback and social influence) and the underlying forms of measures were described in each case along with effect sizes. This classification should provide guidelines for the later implementation of the measures, both for the expectation management and the evaluation. As an example, two bonus systems were derived from the pool of measures, which are adapted to the residents in the demonstration districts.

31.4.4 Energy Justice through Socially Responsible Renovation with a Stable Rent Including Heating

There is great potential for socially responsible measures in existing and new buildings in highly efficient buildings. These can create a balance between economic efficiency of the measures on the part of the owners and affordable housing on the part of the tenants. In a socially mixed district like Überlingen, focus groups and surveys are used to gain insights into the different needs of tenants and to collect information for a needs and values analysis. Based on the findings, differentiated rent models and recommendations for action are developed.

As a first step, an analysis of the relevant players (landlords, tenants, etc) and focus group meetings were conducted to understand the relevant participants and groups of actors involved with their respective roles and motives. This facilitates communication in the project process and enables the concrete involvement of each participant in the corresponding project phases and the early identification of possible reservations.

In addition to an associative approach to the analysis of needs and values, questions were also asked about the understanding of a climate-neutral quarter. Ecological, social, financial and cultural aspects were mentioned. The opinion was expressed that the landlord should treat the building with care, protect the building stock and use renewable energies. In principle, the participants of the focus group were positive about alternative rent models. Transparency and the ability to take action were also mentioned as important values. Further participation events could provide more in-depth insights into the values and goals of the participants and stakeholder groups. Already planned meetings have been postponed due to the COVID-19 pandemic. Written explanations were developed to inform the new tenants about the special features of the quarter and the goals of the research project. This is very much appreciated, which was also reflected in the positive feedback at the open house day in autumn 2021.

The concrete conclusions and recommendations for action are currently being developed. What is already apparent, is a pronounced need for information and communication of the residents on the technologies used, but also with regard to human-technology interaction, for example, on adequate handling of the ventilation system in the apartment. A good combination of comfort and energy efficiency is essential in order to achieve acceptance for a climate-neutral energy supply.

31.5 Tools and their Practical Implementation in the Demonstration Districts

The work will result in a total of four tools for concrete tasks, which will be tested in the districts and cities and should be transferable to other districts in the same way as the results from chapter 31.3.

31.5.1 Quarter App for Consumer Training

The quarter app for consumer training contains tips and Q&As for residents on how to live climate-consciously, as well as the visualisation of various consumption parameters (e.g. power consumption) at household and district level.

In order to establish an energy-saving and sustainable behaviour among residents, apps offer modern technical support. To show the residents of the districts their energy consumption, the quarter app gives them visual feedback on their individual consumption (electricity, heat, hot and cold water) on a household basis, depending on the availability of data, and puts this in relation to the consumption in the entire district. In addition, the app can create cost forecasts for energy consumption and offers the option to set reduction targets for one's own consumption. Through the interface to the "GridOptimizer", tips can also be given depending on the weather forecast, e.g. information on times with high photovoltaic yields. In this way, the quarter app dynamically and contextually encourages climate-friendly behaviour.

Moreover, the quarter app serves to provide information and educate people about ways to live more sustainably. It contains of a multitude of questions and suitable answers on the topic of saving energy, as well as many energy-saving tips from the areas of electricity, heating, water and mobility. Gamification elements such as an award system, in which the next level (from chick to district polar bear) can be reached by completing tasks, provide a playful way of getting to know the app and support district residents in an energy- and environmentally-conscious lifestyle. In addition to these core functionalities, the integration of further services is conceivable, such as the integration of car sharing or departure times of public transport.

So far, the catalogue of requirements for the quarter app has been developed, which serves as a starting point for further quarter app development. In addition, an extended data protection concept for the project was drafted and finalised. The quarter app is currently still under development, but has already been tested within the project and with the first residents, and valuable practical insights have been gained (e.g. data requirements for visualisation, preferences of users in the front-end design). The first generalisable findings and project results have also already been published. (Bonenberger/Graf-Drasch/Meindl 2021)

31.5.2 "Klimaneutral Easy" for Designing Climate-Neutral Districts

Based on the solution sets for a climate-neutral energy supply of districts from chapter 31.3.2, the tool "Klimaneutral Easy" will enable the user to find suitable solutions when planning a district. The quarter is configured in a few steps and the possible energy supply components are limited and preferences are specified. The application then determines concepts adapted to the district with a climate-neutral energy supply in the annual balance.

The tool will be available as an easy-to-use web-based application. The calculations are based on an extension of the District Energy Concept Advisor (District ECA). The previous version of the District ECA enables the energy demand calculation of urban districts according to the boundary conditions of DIN V 18599 plus an approach for user electricity. Within the scope of the project, these will be transferred into a web-based application and supplemented by further central supply variants. For this purpose, the tool is given a selection option for settlement typologies, which also allows combinations of these (step one of the application). In a next step, different German climate regions can be selected. In the third step, the user provides information on limiting factors in the project area, which are used to narrow down suitable supply concepts.

To facilitate the selection of suitable climate-neutral supply concepts for the individual districts, a yes/no questionnaire was developed, which asks for the necessary criteria in an easy-to-understand manner. It was drawn up together with the municipal partners in order to address not only the purely energy-related questions, but also other questions from municipalities and cities, such as questions of monument protection, combustion bans or the use of geothermal energy.

After completing the data entry, the climate-neutral solutions are automatically applied to the entered district. The user then receives a compilation of the evaluation parameters for the existing building or the previous planning as well as for the individual climate-neutral solutions. These include information on technologies (e.g. required lengths of geothermal probes, geothermal collector area, photovoltaic areas) as well as investment, energy and compensation costs. Depending on the user focus, the results can be filtered from an investor’s perspective, a resident’s perspective or a macro-economic perspective.

31.5.3 GridOptimizer

In order to optimise the use of locally generated renewable energy, a “self-learning” information medium was developed that encourages the user to adopt a consumption behaviour that is positive for the grid/district and cost-effective for the user with the help of electricity demand data, heat demand data and a forecast of the amount of renewable energy generated (based on weather forecasts).

In GridOptimizer, a self-learning algorithm was implemented that analyses large amounts of data (e.g. measured values) and draws conclusions from them in order to then make predictions about photovoltaic yield and electricity consumption. This part of artificial intelligence is also known as machine learning and comprises four different types. Relevant for the GridOptimizer are supervised learning (learning according to predefined rules) and unsupervised learning (recognising and evaluating patterns and self-optimisation).

In the first stage of development, the participating households receive information on how they can act in ways that optimise the (electricity) system. For this purpose, messages are made available on the users’ smartphones via the quarter app. As an incentive, a local energy tariff was developed that takes into account the local radiation supply and/or the current electricity price on the Leipzig electricity exchange, depending on the optimisation goal. As a further development, remote control of shiftable loads could be implemented by the GridOptimizer. The prerequisite for this is that the participating households are equipped with communication units or “smart” household appliances that enable remote access.

Controllable processes in residential buildings include so called white goods (washing machines, dishwashers, dryers, refrigerators), heat generators (heat pump, combined heat and power unit), electric vehicles, other charging stations as well as thermal and electrical storage units. The controllable white goods comprise a total of around 35% of the user electricity of households. In various field tests, load shifts of up to 10% could be determined.

The algorithm includes two separate artificial intelligence models: the photovoltaic power forecast and the residential electricity consumption. The algorithm development for the photovoltaic power forecast is almost completed. For this, the artificial intelligence was trained using existing photovoltaic yield data. The trained artificial intelligence already forecasts the photovoltaic yield of test data with a high degree of accuracy (coefficient of determination of 98%, mean absolute error 2.33). Various measured apartment buildings were selected as training data for the prediction of electricity consumption, their data processed and used as a learning data set.

The concrete implementation of the GridOptimizer in the two demonstration districts poses great challenges. Currently, a flat-rate electricity tariff is offered in Überlingen, which works without the variables that the GridOptimizer would use. The experience of the electricity provider shows that tenants generally look for simplicity and transparency in an electricity tariff. More complex electricity tariffs lead to tenants hesitating when choosing an electricity tariff and preferring a “simpler” electricity tariff to the solar landlord-to-tenant electricity tariff. In Stuttgart, no landlord-to-tenant electricity provider for the solar energy has yet been chosen. As soon as this has been determined, discussions are planned to talk about the willingness for variable tariffs.

31.5.4 Life Cycle Assessment Module for “District ECA”

To integrate the analysis of environmental aspects, the urban planning tool District ECA (District ECA 2022) will be extended by a module for life cycle assessment (LCA). For this purpose, it is necessary to implement the different user perspectives, the district context with new construction, existing infrastructure and refurbishment activities (both for buildings and energy concepts) as well as LCA methodological requirements through suitable functionality, data exchange and interfaces.

With the realisation of the life cycle assessment module, the user will be able to estimate the potential contribution to climate change or the use of non-renewable primary energy for the district by designing a particular energy supply concept from a life cycle perspective. The user will also be able to identify potential additional environmental impacts out of constructive aspects (keyword: grey energy) in order to achieve climate neutrality not only in district operation.

The implementation is based on specific requirements for the data model, the data structures, the data content for import and export and possible hierarchy levels.

These are currently being tested and refined as part of the setup of a mock-up and corresponding use cases. Thereby, energy requirements of the District ECA planning tool are brought into line with requirements for the building and district life cycle assessment with the help of the tool Generis® (GENERIS 2022). The workflow for implementation provides for the exchange of data between the two tools, including the building construction as well as the technical systems. Different residential and non-residential buildings with different energy standards are used to provide specific LCA results for the building construction. For the technical systems of the energy concept as well as possible compensation approaches (through photovoltaic, etc.), information on the system type, the energy sources or fuels used and specific performance data are implemented to derive of environmental information for decision support.

31.6 Conclusion

The developments of recent years clearly show the importance of the goals pursued in this project. The development of a climate-neutral energy supply in districts and its accelerated implementation contributes significantly to achieving the climate goals, to which the Federal Republic of Germany committed itself in Paris within the framework of the Conference of the Parties COP 21. In this context, lighthouse projects such as “STADTQUARTIER 2050” represent a bridge to widespread implementation. In addition to the technical efficiency of the buildings and the energy supply, it is also important that the residents are involved, which is achieved in this research project through participation approaches and apps.

The skills, action guidelines and tools developed in this project can help other municipalities to faster reach climate-neutral energy supply-systems for their quarters. Networking within and outside of this project contributes to this in many ways, which becomes apparent through the examples collected in this book.

The integrated, interwoven approach between the implementation in the demonstration districts and the technical issues, linked by the social science research and supported by the practical application tools, shows the importance of continuous interdisciplinary cooperation not only between the participating partners but in the broader society as well.

Network partners STADTQUARTIER 2050

STADTQUARTIER 2050 is embedded in the Solar Building/Energy Efficient City funding initiative as one of six funded projects in Germany. Eleven partners from research, housing, utility, municipality and industry form the STADTQURTIER 2050 team, led by the city of Stuttgart.

Table 31.1: Network partners of the project STADTQUARTIER 2050.

1	Landeshauptstadt Stuttgart – Amt für Umweltschutz	Gaisburgstr. 4	70182 Stuttgart
2	Stadt Überlingen – Abteilung Stadtplanung	Bahnhofstr. 4	88662 Überlingen
3	Fraunhofer-Gesellschaft e.V. – Institut für Bauphysik (IBP)	Nobelstr. 12	70569 Stuttgart
	Fraunhofer-Gesellschaft e.V. – Institut für Angewandte Informationstechnik (FIT) – Kernkompetenzzentrum Finanz- & Informationsmanagement	Alter Postweg 101	86159 Augsburg
4	Universität Stuttgart – Institut für Werkstoffe im Bauwesen (IWB)	Pfaffenwaldring 4	70569 Stuttgart
5	Baugenossenschaft Überlingen eG	Anna-Zentgraf-Str. 15	88662 Überlingen
6	puren GmbH	Rengoldshauser Str. 4	88662 Überlingen
7	Forschungsinstitut für Wärmeschutz e.V. (FIW)	Lochhamer Schlag 4	82166 Gräfelfing
8	Institut für Ressourceneffizienz und Energiestrategien IREES GmbH	Durlacher Allee 77	76131 Karlsruhe
9	Energieagentur Ravensburg gGmbH	Zeppelinstr. 16	88212 Ravensburg
10	Stadtwerk am See GmbH & Co. KG	Kurt-Wilde-Str. 10	88662 Überlingen
11	Energiedienste der Landeshauptstadt Stuttgart	Kesselstr. 21–23	70327 Stuttgart
	Associated Partners:		
12	Saint-Gobain Deutschland	Krefelder Str. 195	52070 Aachen
13	Stuttgarter Wohnungs- und Städtebaugesellschaft mbH (SWSG)	Augsburger Str. 696	70329 Stuttgart

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Johannes Schrade, Micha Illner, Heike Erhorn-Kluttig, Hans Erhorn

32 Solutions for Climate-Neutral District Concepts

Summary: The transformation of settlements and their infrastructure towards climate-neutral districts is a central task of municipal climate protection. The research project STADTQUARTIER 2050 investigated the challenges acting stakeholders face when developing and implementing climate-neutral supply concepts as well as methodological approaches and tools to support the planning process. Based on a literature review and the experiences in the partner municipalities, suitable approaches were compiled and a standardised assessment procedure for the early planning phase was developed. The findings were summarized into a guideline that aims to describe a consistent pre-selection procedure for climate-neutral energy supply concepts for districts. The generic approach of the guideline forms the theoretical basis for a newly developed web-based planning tool for energy-related district development. In this paper, the methodological basis of the tool development is presented and the new planning tool is applied to two demonstration projects in the partner municipalities Stuttgart and Überlingen.

32.1 Introduction

Choosing suitable supply concepts for new or existing districts poses great challenges for the acting stakeholders and decision-makers in municipalities. In the process they must deal with multi-layered, sometimes conflicting interests. For example, next to the important issues of climate protection, affordable housing, maintaining security of supply and adapting to climate change, the partial interests of owners, investors and operators must also be taken into account. In addition, plenty of potentially promising technologies as well as settlement-specific framework conditions and political objectives can complicate the development of desirable solutions. (BBSR 2017a)

An analysis of existing municipal planning processes in the field of energy-related development of districts showed that promising approaches already exist. (BMVBS 2012) However their application is highly dependent on the qualifications and intentions of the acting stakeholders. Therefore, the decision for or against individual supply concepts is not always comprehensible. In some cases, the questions also arise whether all suitable energy supply variants were considered and under which aspects the selection was narrowed down and prioritised.

Johannes Schrade, Micha Illner, Heike Erhorn-Kluttig, Hans Erhorn, Fraunhofer IBP

https://doi.org/10.1515/9783110777567-032

For a more transparent decision-making process and objective selection of possible supply concepts, tools were developed as part of the research project STADTQUARTIER 2050 (Fraunhofer 2019) to support the involved stakeholders. For this purpose, common supply concepts and innovative solution sets for a climate-neutral energy supply of districts were collected and evaluated regarding their strengths and weaknesses. A procedure for the energetic and monetary evaluation of the solution sets was developed for the early planning phase and a list of limiting factors for the different supply concepts was compiled.

The actual tool development is divided into two parts. The methodological principles of the evaluation procedure as well as the application to homogeneous settlement structures are described in “Guideline for climate-neutral districts”. The software tool “Klimaneutral Easy” is based on the generic approach of the guideline and provides the user with additional functionalities. This article presents the two instruments and explains their benefits for the development of climate-neutral districts.

32.2 Climate-Neutral Energy Supply for Districts

In the research project conducted, the goal of a climate-neutral, district-based energy supply is understood as an annual balance of the greenhouse gas emissions released by the building operation (heat and power supply, incl. user electricity). (Fraunhofer 2019) For this purpose, the greenhouse gases are converted into an amount of CO_2 corresponding to the effect (CO_2 equivalent). The greenhouse gases are allocated according to the polluter-pays principle. Generally, the scope of the balance can be extended to include emissions from mobility, consumption and the construction, maintenance and disposal of buildings and infrastructure, however, the narrower scope of consideration is already very ambitious for certain settlement typologies. (dena 2021)

There are many possible solutions for a climate-neutral energy supply for urban districts. They can be designed as a decentralised building-by-building supply, centralised district-based supply or cross-district supply. For a future-proof and cost-stable supply, the development of locally available renewable resources and the greatest possible renunciation of climate-damaging fossil fuels such as hard coal, lignite or heating oil should be aimed for. The use of natural gas is to be limited as far as possible to peak load coverage or to plants with combined heat and power generation. The remaining greenhouse gas emissions are to be offset by credits for photovoltaic electricity feed-in or certificates. Alternatively, biogenic fuels are to be used.

In principle, there is a wide range of possible supply solutions. In the selection made, the most common solutions with a broad availability and without too many technical challenges were considered.

Table 32.1 shows a collection of selected decentralised concepts for a balanced climate-neutral energy supply. What these supply solutions have in common is that heat is supplied on a building-by-building basis and no heat distribution networks are required. In most of the concepts, locally available resources such as solar energy, geothermal energy, groundwater and outdoor air are integrated. Two variants rely on the import of renewable energies in the form of biomass. The gas combined heat and power and fuel cell variants aim for high efficiency in the conversion of gas into heat and electricity. In the long term, all variants with gas components will have to switch to biogenic or synthetic fuels, as the compensatory effect of photovoltaic electricity fed into the grid will gradually diminish due to the increasing share of renewable energies in the grid.

Table 32.1: Overview of selected decentralised solution sets for a climate-neutral energy supply of urban districts.

Heat generators	Renewable heat source	Peak load generators
Air-water heat pump	Outside air	Electrical heating cartridge
Brine-water heat pump with ground probes	Geothermal energy	
Brine-water heat pump with PVT collectors	Outside air and solar	
Water-water heat pump	Ground water	
Gas condensing boiler with solar thermal DHW generation / solar thermal heating support	Solar	Gas condensing boiler
Gas condensing boiler with exhaust air heat pump	Exhaust air	Gas condensing boiler
Biomass boiler	Biomass	
Biomass boiler with solar thermal heating support	Biomass and solar	Biomass boiler
Gas CHP	Biogas (if applicable)	Gas condensing boiler
Fuel cell	Biogas (if applicable)	Gas condensing boiler

Selected centralised district supply concepts are listed in Table 32.2. The centralised supply concepts differ from decentralised supply concepts in that the heat is generated centrally in the district and the generated heat is distributed to the individual buildings via heating networks. The heat is transferred to the buildings in transfer stations that hydraulically decouple the buildings from the heating network. The heat networks can be designed as two, three or four pipe networks, whereby three and four pipe networks offer the advantage of transporting heat to the consumer at two different temperature levels.

A special feature is the so-called “cold local district heating”. Here, a heat transfer medium is distributed to the buildings via an uninsulated distribution network located in the ground. The temperature level of the supply flow of the cold local district heat approximately corresponds to the ground temperature. The actual temperature rise is decentralised in the connected buildings by brine-to-water heat pumps, which use the cold local district heat as a heat source.

Table 32.2: Overview of selected central solution sets for a climate-neutral energy supply of urban districts.

Heat generators	Renewable heat source	Peak load generators
Brine-water heat pump with ground probes	Geothermal energy	
Brine-water heat pump with agrothermal energy	Geothermal energy	
Brine-water heat pump connected to sewage water heat	Sewage water	
Gas CHP with solar thermal heating support	Solar	Gas condensing boiler
Biomass CHP	Biomass	Biomass boiler
Biomass boiler with solar thermal heating support	Biomass and Solar	Biomass boiler
Cold local district heating with ground probes	Geothermal energy	
Cold local district heating with ground collector	Geothermal energy	
Cold local district heating connected to sewage water heat	Sewage water	

A grid-connected heat supply has several advantages over decentralised solutions. (UBA 2020a) For example, positive economies of scale can be achieved in terms of investment costs, as the costs per installed kilowatt of capacity decrease with increasing system size. Moreover, the efficiency often increases with the size of the system, which is noticeable both in terms of energy consumption and running costs. The centralisation of heat generation also reduces the costs for maintenance and repairs. Other positive features are easier integration of renewable energies and reduced space requirements for building services in the individual buildings. However, central heat generation requires additional investment in a heating network. The heat distribution in the district is also associated with higher distribution losses and a non-negligible amount of electricity is required for the network pumps.

Furthermore, it is also possible to connect districts to an existing district heating system. In this case, the buildings can be connected to the district heating individually, which corresponds to a decentralised supply concept, or the district heating is transferred to a separate district heating network at a central point. Subordinate heating networks can usually be operated with lower system temperatures to also make a connection to the return flow of the district heating possible.

32.3 Municipal Heat Planning

An important component of the transformation of cities towards climate neutrality is municipal heat planning. It is an informal planning tool for identifying energy development potential with the aim of reducing energy demand and ensuring a sustainable energy supply. (LHS 2019)

An integral and independent part of this municipal heat planning is the municipal heat planning, which describes a long-term planning process for the development of a sustainable heat supply. (KEA NI 2019) According to the law for further development of climate protection in Baden-Württemberg, all large district cities and urban districts in this federal state are obliged to develop a municipal heating plan by 31 December 2023 (Landtag BW 2013) containing the following elements:

1. inventory analysis of the heat demand and the supply infrastructure
2. potential analysis of energy efficiency, renewable energies and waste heat
3. development of a target scenario for climate neutrality
4. development of an action strategy including a catalogue of measures to increase energy efficiency and minimise greenhouse gas emissions.

The municipal heating plan forms a sound basis for the development and implementation of energy-related district concepts. Based on this information, focus areas for concrete implementation can be identified, area analyses can be carried out and options for future energy supply concepts can be determined. The participants in this early planning phase are usually district managers and urban planners acting on behalf of public decision-makers. The results of this preliminary investigation serve as a basis for coordination discussions with potential investors and operators as well as for the tendering of further planning services.

In the following preliminary planning phase, engineering consultants are commissioned to examine the feasibility and prepare a cost estimate. The planning process should be accompanied by public relations work, and the building owners in the examined area should be specifically informed and involved in the project development.

The preliminary planning is followed by the decision process on the implementation. For this, the interests of the owners, residents, investors, operators and the municipality must be united before the concrete planning and realisation of the construction measures can begin. This step proves to be particularly challenging in practice, as the partial interests of each stakeholder involved can vary greatly.

For a high approval rate, a transparent procedure with early involvement of the participants in the examined area and an objective presentation of suitable concepts that enable climate-neutral district supply is important. The advantages and disadvantages of the respective supply solutions should be made clear, considering the different stakeholders' interests.

32.4 Instruments for Concept Development

While the municipal heating plan provides the regulatory framework for a climate-neutral heating supply, an appropriate tool contributing to the objective selection of suitable climate-neutral supply concepts is still missing. As part of the research project STADTQUARTIER 2050 (Fraunhofer 2019), two instruments were developed for this purpose. Their functionality and applicability are presented below. A detailed description of the methodological background can be found in the guideline. (Schrade/Illner/Erhorn-Kluttig et al. 2022)

The two newly developed instruments for the development of climate-neutral district supply concepts consist of a guideline and a software tool. The guideline describes a standardised procedure for the pre-selection of climate-neutral energy concepts for districts and enables an energetic and monetary evaluation of different solution sets based on a table procedure with pre-calculated values while taking the different interests of the stakeholders involved into consideration.

The software tool "Klimaneutral Easy", on the other hand, is a further development of the generic approach described in the guideline. It provides further options for adapting project boundary conditions and mapping the project area more precisely. The software tool also has additional filter functions for the selection process and a result output with concrete numerical values. (Fraunhofer 2022)

The two tools are intended to provide a simple, low-threshold introduction to energy-related district planning. Users are guided in the selection of suitable climate-neutral supply concepts and a transparent, objective and generally recognised methodology is provided for the evaluation, prioritisation and narrowing down of potential supply concepts. The results can be used as a foundation for further investigations and serve as a decision-making basis for the participants.

The most important target groups addressed by the newly developed tools are district managers and urban planners acting on behalf of public decision–makers. The depth of information and preparation of results are tailored to the needs of these target groups but interested housing associations and energy suppliers can also use the guideline and the software solution to carry out assessments of various district solutions.

32.4.1 Methodological Principles

To enable a smooth start, relevant characteristics from existing settlement typologies (Roth/Häubi 1981, Blesl 2002) were compiled for the most common types of residential settlements in Germany. The data sets include information on the predominant building types, their average building age and floor area, on settlement density such as the number of buildings and living space per settlement area, as well as on the road infrastructure of the settlement such as the distance from the buildings to the street and the total street length in the district.

For the modelling of the buildings, archetype buildings from the “Deutsche Gebäudetypologie” (building typology of Germany) (Loga/Stein/Diefenbach et al. 2015) that include all building ages are used. The building age distribution in Germany is taken as a basis and average geometric parameters for the net floor area, heated volume, roof, exterior wall and windows are derived from the typical example buildings of the German building typology.

Four energy levels are examined in a variant calculation. For the unrefurbished existing building stock, an average thermal insulation level according to Federal Ministry for Economic Affairs and Climate Action (BMWK/BMI 2020) is assumed for the building age between 1969 and 1978. For new construction and refurbishment projects, the requirement levels according to the federal subsidy for efficient buildings for the Efficiency House 55 (EG 55) and the Efficiency House 40 (EG 40) are considered. In addition, a moderate refurbishment level according to Efficiency House 100 (EG 100) is also regarded for the refurbishment.

In addition to the energy level of the building envelope, three different ventilation concepts are available. Possible variants are supply and exhaust air systems with heat recovery, exhaust air systems and window ventilation. In the guideline, the ventilation concepts are linked to the building type and the thermal insulation level, while in the software solution an individual configuration is possible.

The energy assessment of the buildings and the decentralised supply concepts are carried out by means of monthly balance procedures according to DIN V 18599:2018–09 using the standard user profiles for residential buildings. A batch tool was used for the variant calculation, which enables a high–performance serial analysis based on the calculation kernel for DIN V 18599 developed at Fraunhofer IBP. The result is a calculation of the annual final energy demand subdivided in energy sources as well as the heating load, the required thermal output for domestic hot water preparation and the required volume flow for the ventilation systems.

The energy assessment of the central heat supply concepts is based on the results of the building modelling. For heat generators, which are not covered by DIN V 18599:2018–09, separate calculation models are used.

The modelling of heat networks is based on the characteristics specific to the settlement type. The length of the main distribution pipe results from the total length of the streets in the area, while the house connection pipes are determined using the average distance between building and street. The dimensioning of the pipe diameters is simplified for a three-line heating network with a pressure loss of 100 Pascal per metre. (Dötsch/Taschenberger/Schönberg 1998)

The pressure loss is calculated at the lowest pressure point of the local heating network assuming that the network length to the lowest pressure point is one third of the total length, the necessary pressure difference in the house stations is 1 bar (Nussbaumer/Thalmann/Jenni et al. 2017) and the pressure losses in the house stations is 200 mbar for the heat exchanger and control valve.

The electrical power for the network pump results from the pressure loss and the efficiency of the pump (assumption 60%) and the full load hours of the connected consumers. The heat losses of the distribution network are calculated as a function of the operating temperature, floor temperature, network length and length-related heat transfer coefficient of the pipes. The operating temperature of the heating network is derived in a simplified way from the temperature requirements of the connected buildings as a function of the area-specific heating load.

The user electricity for lighting and electrical household appliances is primarily dependent on the household size. (Co2online 2021, Frondel/Andor/Ritter et al. 2015) Based on the distribution of household size per building type (Statistikportal 2011), the average area-specific user electricity consumption ranges between 20 kWh/(m^2a) for single–family houses and 28 kWh/(m^2a) for the remaining building types.

For the determination of greenhouse gas emissions and energy costs, greenhouse gas emission factors according to DIN V 18599–1 and cost parameters for the year 2020 (BMWK 2021) are used. In the case of district heating, two extreme forms are considered in the guideline. On the one hand, conventional district heating from a coal-fired power plant, and on the other hand, renewable district heating from a wood-fired heating plant. The characteristic values used are shown in the following table. For the calculation of the energy costs, an average annual price increase of 5% is assumed.

Table 32.3: Assumed energy prices and greenhouse gas emission factors.

Energy sources	Price (gross, 2020) [Cent/kWh]	Greenhouse gas emission factor (2019) [g/kWh]
Gas	6,8	240
District heating (coal-fired power plant)	8,5	240
District heating (biomass-fired heating plant)	9,5	60
Wood pellets	5,0	40
Domestic electricity	31,2	550
Heating current	23,7	550
Photovoltaic electricity (supply)	7,0	−550 (credit)

To ensure the climate neutrality of a supply concept, existing emissions must be compensated for through appropriate measures. For this purpose, roof surfaces in the district are equipped with photovoltaics as much as possible and the surplus electricity that cannot be consumed within the district is fed into the grid. The photovoltaic electricity fed into the grid is credited with 550 g/kWh. For the emissions remaining in the annual balance that cannot be compensated through local energy production from renewable energies, external compensation measures are considered through the purchase of emission certificates. The compensation costs are estimated at €220 per tonne of CO_2. (UBA 2020b)

The required investment costs for the implementation of a supply concept are estimated based on characteristic cost values. The area-specific costs for thermal insulation are estimated depending on the U-value per building component. (BBSR 2017) For the output-specific costs of heat and electricity generation, cost curves with a degressive course for increasing output size are used. (BBSR 2017b, Hinz 2015, Stuible/Zech/Ullrich et al. 2017, Wolff/Jagnow 2011)

32.4.2 Guideline for Climate-Neutral Districts

The procedure described in the guideline for identifying a suitable supply concept can be divided into five sub-steps. At the beginning of the selection process, the user specifies the relevant boundary conditions of the district. For this purpose, the district under investigation is assigned to a settlement type, a suitable climate zone is selected for the location and it is specified whether it is a new construction or a refurbishment project.

Depending on the settlement type and climate zone, an evaluation matrix from the appendix of the guideline is then selected for the comparison of variants. In the third step, site-specific limiting factors are recorded to narrow down the selection of possible supply concepts.

Subsequently, the remaining supply variants can be further limited by means of soft factors. Finally, it is possible to define a prioritisation rule for the monetary evaluation of the supply variants. For this purpose, the perspective of the investor, the occupants, the external compensation or the macro-economy can be taken. The general procedure is visualised in Figure 32.1.

For the selection of the settlement type, five types with predominantly residential premises are available to the user:

- ST 2: Single-family house settlement
- ST 4: Estate of terraced houses
- ST 5b: Row development with small and larger apartment buildings
- ST 6: Row development with large apartment buildings or high-rise buildings
- ST 7a: Low-density block development

Furthermore, the user can choose between three climate zones, whereby in addition to the reference climate of Germany (location Potsdam), a less beneficial location with

Figure 32.1: General procedure for selecting a suitable supply concept for districts.

a cold winter and low solar radiation (Fichtelberg) and a more beneficial location with a mild winter and high radiation (Mannheim) can be selected.

The evaluation matrix in the appendix of the guideline shows a monetary evaluation of the supply concepts, considering investment costs, energy costs, compensation costs and the macro-economic perspective (see Figure 32.2). The monetary evaluation does not consider subsidy measures, as these can change quickly and vary from region to region. The result is not shown in absolute figures, but a comparative view is made between the supply concepts. The classification is based on quintiles, with the best 20% of the concepts falling into category 1 and the worst 20% into category 5.

Boundary conditions	Climate zone	04_Potsdam (moderate climate)															
	Type of settlement	ST 2 - Single-family house settlement															
	Assessment criterion	Investment costs				Energy costs				Compensation costs				Macro-economic perspective			
	Energy performance level	EG 40	EG 55	GEG-Ref.	Existing	EG 40	EG 55	GEG-Ref.	Existing	EG 40	EG 55	GEG-Ref.	Existing	EG 40	EG 55	GEG-Ref.	Existing
Decentralised energy supply concepts	Air-water heat pump	5	3	2	1	2	3	4	5	0	0	0	5	3	2	3	5
	Brine-water heat pump with ground probes	5	4	3	2	1	2	3	5	0	0	0	5	4	3	4	5
	Brine-water heat pump with PVT collectors	5	4	4	2	2	2	4	5	0	0	0	5	5	4	4	5
	Water-water heat pump	5	4	3	1	1	1	3	4	0	0	0	5	4	2	2	5
	Gas condensing boiler with solar thermal DHW generation	4	2	2	1	1	3	4	5	0	0	4	5	2	2	3	5
	Gas condensing boiler with solar thermal heating support	4	2	2	1	1	3	4	5	0	0	4	5	2	2	3	5
	Gas condensing boiler with exhaust air heat pump	5	3	2	1	2	2	4	5	0	0	0	5	4	2	3	5
	Biomass boiler	5	3	2	1	1	1	3	4	0	0	0	0	2	1	1	1
	Biomass boiler with solar thermal DHW generation	5	4	3	1	1	1	2	4	0	0	0	0	2	1	1	2
	Biomass boiler with solar thermal heating support	5	4	3	1	1	1	2	4	0	0	0	0	3	1	1	2
	Gas CHP with gas condensing boiler	4	3	2	1	2	3	4	5	0	0	0	5	2	1	2	4
	Fuel cell with gas condensing boiler	5	4	3	1	2	3	4	5	0	0	0	5	4	4	5	5
Centralised energy supply concepts	Brine-water heat pump with ground probes	5	3	2	1	2	3	4	5	0	0	4	5	4	3	3	5
	Brine-water heat pump with agrothermal energy	5	3	2	1	2	3	4	5	0	0	4	5	4	3	3	5
	Brine-water heat pump connected to sewage water heat	5	3	3	1	2	3	4	5	0	0	0	5	4	2	3	5
	Gas CHP and solar thermal heat	5	4	4	2	2	3	4	5	4	4	5	5	4	4	4	5
	Wood chip CHP and wood chip boiler	5	3	3	1	2	3	4	5	0	0	0	0	3	1	1	1
	Wood chip CHP and solar thermal heat	5	4	4	2	1	1	1	3	0	0	0	0	2	1	1	1
	Cold local district heating with ground probes	5	4	3	2	1	2	3	5	0	0	0	5	4	2	3	5
	Cold local district heating with ground collector	5	4	3	1	2	2	4	5	0	0	0	5	4	3	4	5
	Cold local district heating connected to sewage water heat	5	4	3	1	1	2	3	5	0	0	0	5	4	3	3	5
	District heating (conventional)	4	2	2	1	1	3	4	5	0	0	4	5	2	1	2	5
	District heating (climate neutral)	4	2	2	1	2	3	4	5	0	0	0	0	1	1	1	3

LEGEND: 1 very positive; 2 positive; 3 neutral; 4 negative; 5 very negative; 0 no external compensation required

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Figure 32.2: Monetary evaluation of the supply variants for settlement type 2 – single-family house settlement at the location Potsdam.

Since not every supply concept is equally suitable for every settlement type and every location, the guideline offers a possibility to narrow down the variants. To identify the limiting factors, a questionnaire is available in the appendix of the guideline, which focuses on the existing infrastructure, technical and legal restrictions, and the structural characteristics of the location.

In addition to the limiting factors, the supply options can be further narrowed down using soft evaluation factors. For this purpose, the supply concepts were evaluated regarding their future viability, feasibility, transferability, expandability, climate change adaptation, robustness to climate change and grid supportiveness (see Figure 32.3). The evaluation was carried out qualitatively using a three-stage evaluation system, where '+' stands for positive, 'o' for neutral and '-' for negative. For example, solutions with heat pumps receive a positive rating for future viability, while supply concepts with fossil energy sources and biomass are rated negatively. The basis for this assessment is the limitation of the resources being used and the political significance for the transformation of the energy system. A detailed presentation of the assessment methodology can be found in the guideline. (Schrade/Illner/Erhorn-Kluttig et al. 2022)

32.4.3 Software Tool "Klimaneutral Easy"

The software tool "Klimaneutral Easy" is based on the generic approach of the guideline and provides additional functionalities that contribute to a higher user-friendliness and enable a higher accuracy in the modelling through further adaptation options.

For example, a selection of ten different settlement types with predominantly residential use is available for the quick start. To support the user in selecting the settlement type, settlement profiles with aerial photographs of typical settlement structures are integrated in the software tool. The settlement–specific building and infrastructure data stored in the profile can be overwritten if necessary, for example with data from the municipal heat planning.

A combination of different settlement types is also possible in the software tool, so that heterogeneous districts can be mapped. Likewise, different levels of thermal insulation, ventilation concepts and construction methods can be combined with each other.

The energy assessment of the district can be implemented for all climate zones of DIN V 18599–10. The climatic conditions are considered in the energy demand calculation, potential assessment and rough dimensioning. When drawing up the climate balance, the scope of the balance can be extended to include emissions from grey energy, mobility and consumer goods, if required. The output of results is possible with concrete values for costs, energy demand and emissions, switching between area-specific and absolute values.

		Future viability	Feasibility	Transfer-ability	Expand-ability	Climate change adaption	Robustness	Grid supportive-ness
Decentralised energy supply concepts	Air-water heat pump	+	+	+	+	+	+	+/–
	Brine-water heat pump with ground probes	+	+	o	o	+	+	+/–
	Brine-water heat pump with PVT collectors	+	o	o	+	–	+	+/–
	Water-water heat pump	+	–	–	o	+	-	+/–
	Gas condensing boiler with solar thermal DHW generation	–	+	+	+	–	o	o
	Gas condensing boiler with solar thermal heating support	–	+	+	+	–	o	o
	Gas condensing boiler with exhaust air heat pump	–	o	+	+	o	o	–
	Biomass boiler	–	o	–	o	o	–	o
	Biomass boiler with solar thermal DHW generation	–	o	–	o	–	–	o
	Biomass boiler with solar thermal heating support	–	o	–	o	–	–	o
	Gas CHP with gas condensing boiler	–	o	+	+	o	o	+
	Fuel cell with gas condensing boiler	o	–	+	+	o	o	+
Centralised energy supply concepts	Brine-water heat pump with ground probes	+	+	o	o	+	+	+/–
	Brine-water heat pump with agrothermal energy	+	+	–	–	+	o	+/–
	Brine-water heat pump connected to sewage water heat	+	–	–	–	+	+	+/–
	Gas CHP and solar thermal heat	–	+	–	+	o	o	+
	Wood chip CHP and wood chip boiler	–	+	o	+	o	–	+
	Wood chip CHP and solar thermal heat	–	o	o	+	o	–	o
	Cold local district heating with ground probes	+	o	o	o	+	+	+/–
	Cold local district heating with ground collector	+	o	–	–	+	o	+/–
	Cold local district heating connected to sewage water heat	+	–	–	–	+	+	+/–
	District heating (conventional)	+	+	–	+	o	o	o
	District heating (climate neutral)	–	+	–	+	–	o	o

LEGEND: + positive o neutral – negative

Figure 32.3: Evaluation of the supply concepts based on soft factors.

The software tool is particularly user-friendly when it comes to filtering and prioritising supply options. The selection of possible supply concepts is automatically adapted to limiting factors. Likewise, soft factors can be selected as filter criteria and different perspectives can be combined and weighted when prioritising the variants.

In the future, it is planned to link the software tool to Fraunhofer IBP's own assessment tool for districts, "District ECA" (Erhorn-Kluttig/Erhorn/Weber et al. 2014), which enables a standard-compliant energy assessment of buildings and districts based on the calculation core for DIN V 18599. Upon completion, the software tool will be available free of charge on the website of the research project "STADTQUARTIER 2050". (Fraunhofer 2019)

32.5 Application Examples

The two lighthouse projects for climate-neutral energy supplies in the research project STADTQUARTIER 2050, were used as initial application examples. Despite the same objectives, the two districts in Stuttgart and Überlingen are very different and are therefore well suited to evaluate the functionality of the generic approach. Especially regarding local conditions and restrictions, the two districts differ considerably. While the project in the quarter *Bürgerhospital* in Stuttgart envisages the conversion of an abandoned hospital site to residential purposes and is surrounded by a highly dense metropolitan structure, the project area Hildegardring/Schättlisberg in Überlingen is located on the outskirts of a small medium-sized town. The resulting limiting factors are very different, which is why different approaches to a climate-neutral energy supply are being pursued in both districts. In the following, the two pilot projects are briefly presented and the generic approach of the guideline is applied. Since supply concepts had already been defined for both locations at the time the guideline was completed, the applications of the guideline had no direct influence on the actual choice of energy concept. However, the results of the application examples confirm the usefulness of the guideline as well as the solutions chosen for the respective site.

32.5.1 *Bürgerhospital* in Stuttgart

The project area in Stuttgart covers the inner-city area of the former *Bürgerhospital*. In this general residential area, at least 600 residential units and some small businesses are to be built. Most of the new residential space is to be developed as affordable housing. Most of the existing buildings will be demolished during the conversion and replaced by new buildings. The urban design envisages a perimeter block development with up to eight full storeys arranged around interior open spaces. (Schrade/Erhorn/Erhorn-Kluttig 2020)

As a special challenge, there are various legal and technical restrictions such as a requirement to avoid particulate pollution, anhydride rock in the ground, and restrictions under building law due to emergency water wells, tunnel constructions, thermal water deposits and a tree population worth preserving in the project area.

Applying the procedure described in the guideline results in a selection with two decentralised supply concepts (air-water heat pump, brine-water heat pump with photovoltaic thermal hybrid solar collectors (PVT)) and four centralised supply concepts (local district heating with ground probes or sewage water heat and cold local district heating with ground probes or sewage water heat). In addition, the district heating located in the immediate vicinity could also be used, although it currently still has a high greenhouse gas potential (see Figure 32.4).

	Investment costs		Energy costs		Compensation costs		Macro-economic perspective	
	EG 40	EG 55	EG 40	EG 55	EG 40	EG 55	EG 40	EG 55
Air-water heat pump	5	3	3	4	4	4	5	4
Brine-water heat pump with PVT collectors	5	4	3	4	4	4	5	5
Local district heating with ground probes	5	4	2	2	1	1	3	1
Local district heating with sewage water heat	5	3	1	2	1	1	2	1
Cold local district heating with ground probes	5	3	3	3	1	2	4	2
Cold local district heating connected to sewage water heat	5	4	3	3	1	2	4	2
District heating (conventional)	4	2	2	2	4	5	4	3

LEGEND: 1 very positive 2 positive 3 neutral 4 negative 5 very negative

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Figure 32.4: Selection of suitable supply concepts for the district *Bürgerhospital* in Stuttgart.

From an economic point of view, the two variants with a local district heating network and an energetic building level according to EG 55 prove to be the most suitable. Moreover, with regard to emissions that cannot be compensated for in the project area, the best results can be achieved with the two local district heating concepts, whereby the better thermal protection of the EG 40 has a positive effect. From the residents' point of view, the local district heating concepts with a higher level of thermal protection are also advantageous. From the investor's point of view, the best results are achieved with a connection to the existing district heating network or with a decentralised supply using air-water heat pumps. The local district heating concept with ground probes and sewage water heat supplemented by photovoltaic thermal hybrid solar collectors will actually be implemented in the project. Additionally, an ambitious thermal insulation standard is aimed for. The result showed can be used to illustrate that minimizing the compensation and energy costs were important factors when determining the supply variant.

32.5.2 *Hildegardring/Schättlisberg* in Überlingen

In Überlingen, 180 new residential units are being built directly adjacent to an existing district according to the cooperative principle. The urban design envisages a row development with small and medium-sized apartment buildings. The new buildings are planned as three- and four-storey residential buildings. The district is located on the edge of the town with large open spaces in the immediate vicinity. In direct proximity of the expansion area is the local heating network, which already has a high proportion of renewable energy.

Due to the lack of restrictions limiting the selection of possible supply concepts, almost all solution approaches presented in Chapter 32.2 are generally possible. Following the selection procedure described in the guideline, different levels of investment costs, compensation costs, energy costs and macro-economic perspectives result for each solution. Figure 32.5 shows the six most suitable variants.

	Investment costs		Energy costs		Compensation costs		Macro-economic perspective	
	EG 40	EG 55	EG 40	EG 55	EG 40	EG 55	EG 40	EG 55
Gas condensing boiler with solar thermal heat support	4	2	1	1	4	4	4	2
Biomass boiler	5	3	1	1	2	2	4	2
Local district heating with agrothermal energy	5	4	1	2	1	1	3	1
Local district heating with gas CHP and solar thermal heat	5	4	1	2	1	2	2	1
Local district heating with wood chip CHP and wood chip boiler	5	4	2	2	0	0	3	1
Local district heating with wood chip CHP and solar thermal heat	5	4	1	1	1	1	2	1

LEGEND: 1 very positive; 2 positive; 3 neutral; 4 negative; 5 very negative; 0 no external compensation required

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Figure 32.5: Selection of suitable supply concepts for the district *Hildegardring/Schättlisberg.*

The results show that a local district heating solution with a pure biomass combined heat and power unit could ensure a climate-neutral supply without external compensation. From an economic point of view, the supply solutions combined with the building level according to EG 55 are the most favourable. In terms of energy costs, all selected concepts are very positive. In terms of investment costs, the decentralised supply variants with a lower level of thermal insulation are somewhat more favourable. In the project area in Überlingen, a local district heating solution with a gas combined heat and power unit, biomass boiler and solar thermal system will be implemented. The new buildings will be constructed according to the energy requirements of an Efficiency House 40 Plus. Moreover, a variant was chosen with the lowest possible compensation costs. From an economic point of view, the EG 55-level would have been cheaper, but the additional costs for the increased energy standard are covered through the KfW funding programme.

32.6 Summary and Outlook

Developing climate-neutral supply concepts for districts is crucial to achieve the ambitious but necessary climate protection goals. Combining the partial interests of the stakeholders in the district and offering desirable solutions for the different interest groups prove to be particularly challenging in the planning process. With the “Guideline for climate-neutral districts” and the software tool “Klimaneutral Easy”, participants have two instruments at their disposal that support the selection process in the early planning phase and help to identify suitable solution sets transparently and objectively.

The application of the two instruments to the districts in Stuttgart and Überlingen has confirmed their basic applicability. Furthermore, the application of the tools showed that under the given boundary conditions, the most suitable variants from a macro-economic perspective were chosen in both cases.

In the future, both tools can become an essential component of municipal energy planning. For this purpose, a further test phase by the municipal project partners is planned within the framework of the research project. The final software tool will be available free of charge as a web-based application.

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Sven Leonhardt, Erik Höhne, Tobias Teich, Mirko Bodach,
Pauline Ziegert

33 ZED (Demonstrating Zwickau's Energy Transition): Innovations and Transformation for the Energy Turnaround -Electrical-Thermal Wide Area Synchronous Grid as the Basis for Energy-Efficient and Socially Fair Quarter Development

Summary: The lighthouse project "ZED (Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau's Energy Transition)" demonstrates how energy transition in existing buildings can work under everyday conditions in a socially and environmentally compatible, secure and affordable manner with the help of technical and social innovations. Through the intelligent interaction of thermal and electrical components as well as information technology networking in an integrated electric-thermal wide area synchronous grid for year-round sector coupling, the goals of the funding initiative "Solar Construction/Energy Efficient City" are to be achieved, in particular the increase of energy efficiency, reduction of energy consumption (sufficiency) and decarbonisation. In the systemic, transdisciplinary approach of ZED, the networking of participants and their services as well as the participation of residents are crucial to ensure acceptance and awareness for the innovative solutions. Local knowledge and relevance to everyday life can thus be used in the sense of user-oriented technology development so that these solutions are transferable.

33.1 Introduction

Social upheavals and rapid technological developments require new answers to the question of how we can shape our coexistence in Germany and strengthen cohesion in our society. With the Hightech-Strategy (HTS 2025) the Federal Republic of Germany is outlining perspectives on how Germany can successfully shape its future with research and innovation. It is intended to provide orientation for all participants in the innovation process. The Hightech-Strategy (HTS 2025) focuses the promotion of re-

Sven Leonhardt, Tobias Teich, Mirko Bodach, Westsächsische Hochschule Zwickau
Erik Höhne, Pauline Ziegert, Stadt Zwickau

https://doi.org/10.1515/9783110777567-033

search and innovation on people's needs – for example in the areas of "Health and Social Care", "Sustainability, Climate Protection and Energy", "Mobility", "Urban and Rural Areas", "Security" and "Economy and Work 4.0". It is intended to help place Germany at the forefront of the next technological revolutions in order to keep jobs in Germany and secure our prosperity. The promotion of new technologies accompanies investments in education and training and the involvement of society to prepare people for upcoming changes. The Hightech-Strategy (HTS 2025) creates scope for innovation and organises cooperation in the innovation process. It aims to encourage a wide range of participants to actively shape progress. For this, the Hightech-Strategy (HTS 2025) shows possibilities and offers support. (BMBF 2022)

The research into technological and societal innovations called for by the High-Tech Strategy must be reconciled with the needs of city residents in the district. The project "ZED (Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau's Energy Transition)" which was created with reference to the goals of the 6th Energy Research Programme of the Federal Government, combines the forces of science, business, society and politics in Zwickau (West Saxony) and uses the resulting synergies for higher competitiveness, improvement of supply structures and sustainable prosperity. ZED thus actively contributes to the fulfilment of the climate policy goals of the Federal Republic of Germany as well as the German National Action Plan on Energy Efficiency (NAPE) and helps to implement the Energy Efficiency Strategy for Buildings (ESG), or its successor.

The further expansion of renewable energies can only be achieved through intelligent networking in the district and through combination with energy storage systems, as well as through further development and demonstration of systemic concepts at neighbourhood level.

The main objective of ZED is to develop technologies and methods for the local energy transition and in particular for the heat transition on site and to demonstrate them in a suitable district in Zwickau, Marienthal. In this context, the conception and implementation of electrical-thermal wide area synchronous grid forms the basis for an energetic quarter development for the realisation of zero-emission districts. This requires highly efficient storage technologies and the combination of electrical and thermal overall concepts. This enables an increase in the share of renewable energy sources such as photovoltaics and especially solar and geothermal energy in residential quarters. However, ZED is not intended to create "islands" or typical project districts, rather it is essential that the project is oriented towards urban development and helps to shape it.

Concepts previously developed in Zwickau, for example in the areas of climate protection, mobility or urban development, as well as scientific projects of the University of Applied Sciences Zwickau (WHZ), are to be integrated and expanded and contribute to energy-efficient and socially fair quarter development.[1] In addition to technical developments, social justice plays a key role. In this inter- and transdisciplinary project, it is essential to strive for user-oriented and user-centred technology development. The main objective is therefore to use new technologies and economically viable concepts as well as social science methods to sustainably secure the affordability of housing and actively counteract negative trends such as old-age poverty and energy poverty.[2]

33.2 Project Focus Quarter

The project focuses on demonstrating energy-efficient and socially fair quarter development against the background of current megatrends (Zukunftsinstitut 2018) (climate change, demographic development, etc.) for the particularly vulnerable housing market.

Housing is a basic need and the provision of housing is a fundamental right. The affordability of these essential factors is therefore soon a major socio-political challenge. Urban region with its districts, buildings and (energy) infrastructures is also one of the most important drivers of climate change and represents the basis for sustainable living. (Van Bueren/van Bohemen/Itard et al. 2012) The outstanding importance of the housing industry is underlined by the fact that half of Germany's net fixed assets consist of residential buildings. The demographic development and its serious effects are particularly noticeable in focus regions such as Zwickau, where the average age of individual apartment blocks (Figure 33.1) is over 65 years and are a central starting point for sustainable, intergenerational concepts of self-determined and affordable living.

This demographic tension is increasingly exacerbated by the negative development of the ratio of providers (people in employment subject to social security contributions) to benefit recipients (to recipients of social benefits and especially pension payments) in the social economy context. The current ratio of about three to one (Raffelhüschen/Müller 2011) will be about one to one in less than twenty years. (Kochskämper 2018) This imbalance leads to a reduction in pensioners' incomes and illustrates how dramatically the situation of affordable rents as well as health and energy costs will develop. (Geyer/Steiner 2010) Old-age poverty is therefore one of the greatest social risks of the future in Germany and especially in the focus regions.

The global climatic as well as regional demographic and necessary infrastructural changes result in the demand for restructuring of the technical designs in thermal

1 Projects like: "DEF-suE – Demographic energy-balanced Framework for sustainable urban Environments" or "Freiluftlabor "Neue Mobilität" am Sachsenring; ePay "EMV-Robuste Energieabrechnungsszenarien für Gridkomponenten in der E-Mobilität" / Teilprojekt" – further reading: www.aiis.fh-zwickau.de.

2 Details to the development of the energy-coupled grid and the social and affordable aspect of these net are mentioned in the following chapters.

Figure 33.1: Apartment block in the project quarter in Marienthal.
(source: ZED project)

supply systems. Only with the help of novel concepts and systems defined, planned and demonstrated at neighbourhood level, a sustainably affordable way of life can be realised. Therefore, the topics of environmentally friendly and cost-effective conversion of energy supply (local energy turnaround) and the energy efficiency of districts as well as the creation of age-appropriate, affordable housing are priorities for the sustainable development of urban areas.

For this reason, these topics are considered and analysed holistically in the ZED project. In addition, the technical potential of a holistic and also future economic energy supply in the district represents a further motivation for the municipality and its partners. In the past, quarters were usually supplied centrally with heat and electrical energy. In recent years, there has already been a rethinking and approaches to decentralisation have been pursued. Above all, renewable energy generated by photovoltaic systems for the electrical supply or solar thermal systems for the heat supply have been installed in large numbers. The resulting problem, apart from the now required interoperability of the trades, is the necessary on-site energy storage. (Leonhardt/Leonhardt/Teich 2015)

So far there have been no quarter-specific energy storage systems available on the market that combine electrical and thermal energies and take into account all the requirements of a district. A suitable way to store the energy generated on site and consume it at a later point in time is to combine it into electrical and thermal wide area synchronous grid at economic and socially acceptable prices. In the context of ZED, this was developed through the coupling and storage of electrical and thermal energy as well as the different forms of organisation and is being demonstrated in the real laboratory in order to achieve an increase in the individual efficiencies of the still separate systems, convergence towards a zero-emission quarter and reduction of CO_2 emissions (decarbonisation).

33.3 The Quarter Zwickau Marienthal

The quarter Zwickau Marienthal (Figure 33.2) was selected as a living lab for the implementation of the project "Demonstrating Zwickau`s Energy Transition" for which different supply models are developed, refined and demonstrated. The urban quarter is located in the west of the city of Zwickau. Around 13,500 of the city's total population of around 91,000 live here. This living lab of a local energy transition covers about 106 hectares, of which about 79 hectares are residential.

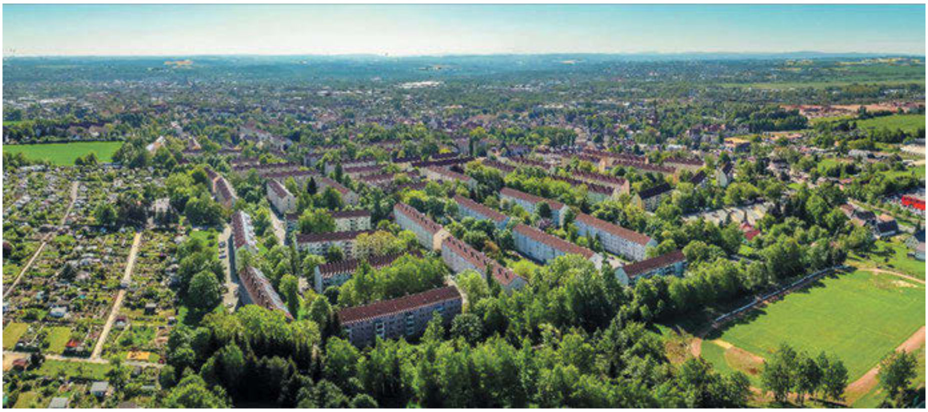

Figure 33.2: The quarter Zwickau Marienthal (detail).
(source: ZED project)

Zwickau's largest housing provider, the municipal subsidiary GGZ, which is represented as a partner in the project, manages 34 residential buildings with about 1024 residential units and a total living space of about 56,320 m^2. The buildings are mainly renovated three- or four-storey GDR-type buildings built between 1957 and 1964 with gas central heating (insulation standard 8/0400 cm/WLG). The hot water supply is provided by electric instantaneous water heaters in most of the residential units. The heat supply is usually provided by natural gas-fired heat generators that supply several buildings with heat via small local heating networks. The heat is transferred to the buildings via a transfer station with hydraulic decoupling. This equalises the pressure level in the main distribution circuits. Heat is transferred to the flats exclusively via panel radiators. The consumption value (heating energy) of the residential buildings in the quarter is an average heat demand of refurbished buildings of about 70 kWh per m^2 and about 3,942,400 kWh per year. In addition to the residential buildings of the major landlord, public buildings (schools, kindergartens, sports facilities, etc.) are also located in the quarter, which are also to be analysed and connected to the developed networks. In addition, all urban functions such as housing, services, commerce, infrastructure and transport are located in the quarter. The age structure in the quarter Marienthal reflects that of the entire city. Approximately 58% of the working-age population is between 16 and 65 years old. About 35% of the people in Marienthal are older than 65. The household structure is equally representative of the overall structure in Zwickau, with about 48.5% single-person households and about 35.5% two-person households.

33.4 Objective and Structure of the ZED Project

The funding initiative “Solar Construction/Energy Efficient City” (PtJ 2017) aims to promote an environmentally friendly, safe and cost-effective transformation of the energy supply in Germany. Therefore, comprehensive lighthouse projects at neighbourhood level are being funded in Module II “Energy-efficient city” – with the aim of addressing the various energy-related aspects from a systemic perspective, from basic research to technology development to demonstration, including socio-ecological aspects. Moreover, it is important to reduce energy consumption, advance sector coupling and gradually decarbonise the entire system through the integration of renewable energies.

The project “ ZED (Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau’s Energy Transition)” is a joint project initiated by the city of Zwickau with twelve other partners. In addition to the city of Zwickau, which as the coordinator of the network focuses primarily on municipal issues, three research institutions with different focal points are involved in the project. The University of Applied Sciences Zwickau (WHZ) is represented in the project by the Chair of Networked Systems in Business Administration, in particular Energy Management, the Chair of Electrical Power Engineering/Renewable Energies and the Chair of Thermal Engineering/Computer-aided Planning Methods, thus setting the focus on these project fields. The Chair of Technical Thermodynamics at University of Technology Chemnitz (TUC) and the Institute of Sociology at Ludwig-Maximilians-University Munich (LMU) complete the scientific partners. The claim of integrated demonstration of the topics of ZED also requires the participation of relevant private-sector actors. The principal actors are the local energy supplier (Zwickauer Energieversorgung GmbH) and the largest housing provider in Zwickau (GGZ), as well as other partners from the fields of infrastructure, health, architecture and mobility. (Leonhardt/Höhne/Neumann et al. 2018)

Since the beginning of the funding in 2017, the ZED Lighthouse has been making a corresponding contribution with its 13 collaborative partners from science and practice and its three pillars “energy infrastructures”, “data bases and planning tools” and “social science issues”: development of technologies and methods for the local energy transition, in particular the on-site heat transition and its demonstration at neighbourhood level in Zwickau, Marienthal (Figure 33.3).

In the original specific project approach, the quarter Marienthal is divided into three sub-areas. For that reason, different approaches to energy supply were analysed, designed and compared with each other.

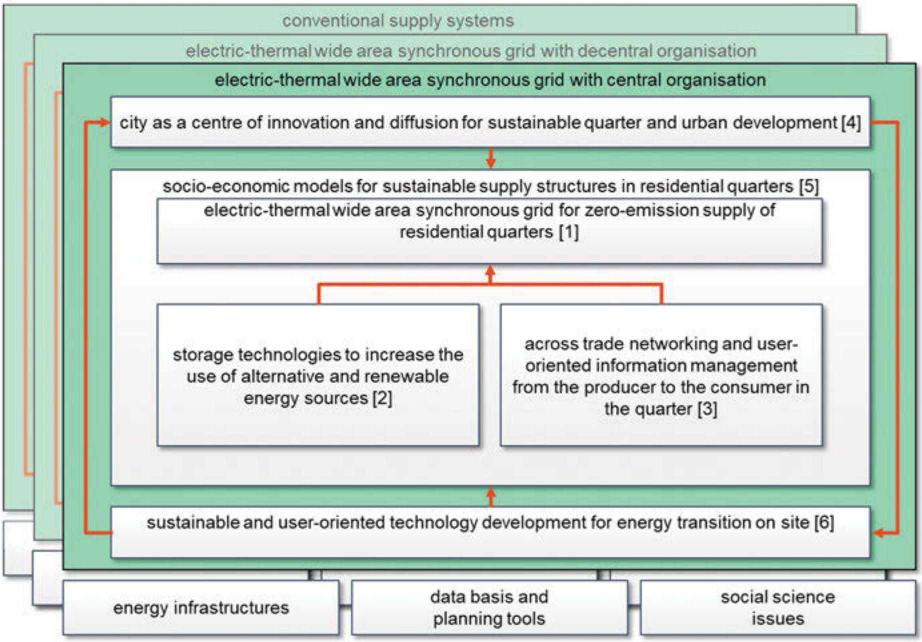

Figure 33.3: Overview of ZED's structure.
(source: ZED)

The starting point for all scientific-technical developments and sociological investigations is a conventional supply system. In a subarea of the living lab, the energy supply system remains unchanged. The existing infrastructure was expanded with additional measurement technology. Thus, a (temporary) digitalisation in the supply network could be achieved, which is also the basis for further analyses and development of methods, e.g. for models of service charge statements. In addition, the area is the starting point for the implementation of socio-scientific quarter analyses and other studies with a socio-scientific background. Last but not least, with the conventional comparison areas, the basis for quarter-internal, energy benchmarking could be created.

In comparison to the conventional system, both a centrally organised and a decentrally organised electric-thermal wide area synchronous grid was designed for supply.

The technical approach of the centralised electric-thermal wide area synchronous grid was designed with the construction of a walk-in power house in the quarter, which serves for monitoring and as a showroom (especially against the background of the transfer concerns of ZED). The integration of different renewable energy sources, such as solar heat, photovoltaics and waste heat, was conceptually investigated for the central integrated system. In addition to the power house, the centrepiece of the system is the highly efficient hot water tank, which guarantees long storage times with low losses and very good stratification behaviour, with simultaneous integration of several heat sources. In order to be able to use different temperature ranges, several high capacity (industrial) heat pumps are to be integrated into the system.

This is contrasted with the approach of a decentrally organised electric-thermal wide area synchronous grid, which applies an innovative working principle of energy flow to individual residential blocks in the quarter. These are connected to each other via an intelligent heating network. In contrast to the conventional heating network, heat is transported bidirectionally in a pair of pipes. It enables to see each client in the network as a source and a sink in a higher-level operating regime of the energy network. The operating principle allows the heat transport medium in a heat network to be conveyed only when heat is required and to run different medium temperatures on partial routes at the same time. In this way the transportation of waste heat or residual heat from the network and storage systems to the place of a sensible use (e.g. home) is possible.

On a more abstract level, ZED addresses structural transformation and innovation processes. (Leonhardt/Höhne/Schneider et al. 2022) The lighthouse project is geared equally towards innovation and transformation theory approaches:

Transformation theories emphasise the simultaneity of change processes because they always proceed co-evolving or even temporally staggered in different levels or sectors, whether (energy) infrastructures, (storage) technologies, services or value orientations and consumption patterns. (Geels 2002, Rotmans/Fischer-Kowalski 2009)

Research on current transformations in the context of energy system transformation and climate protection shows the complexity of control, governance and strategy approaches. In addition to infrastructural-technical path dependencies, actor-specific barriers such as fear of change, protection of vested rights interests or short-term thinking are of great importance in the development, implementation and establishment of innovations. Therefore, the involvement of the most important stakeholders in the "transformation of landscape" is a decisive factor for successful transformation. The active involvement of the different stakeholder levels and analysis of the specific motives, interests, but also knowledge bases, are from this point of view central drivers and success factors for the development of sustainable energy infrastructures and realisation of zero-emission residential quarters such as Zwickau, Marienthal. This is a suitable way to develop specific strategies that, in addition to the challenges posed by the energy transition and climate change, also address the expectations and needs of politics, business and civil society and provide instruments that appear particularly suitable for use in practice and are communicated accordingly. (Leonhardt/Neumann/Gottschalk et al. 2022)

In this way, the ZED project goes beyond the funding initiative right from the start, especially since energy research and policy have also predominantly discussed technical strategies and efficiency measures for decarbonisation for the building stock (Harputlugil/de Wilde 2020). Even in the new German National Action Plan on Energy Efficiency (NAPE 2.0), the demand side of the energy system is now more strongly considered and the previous efficiency policy is expanded to include stakeholder processes, but the policy mix still focuses on reducing energy consumption and CO2 primarily with technical measures. In contrast, user behaviour, socio-technical interactions, cross-sectoral cooperation, social participation or financial participation have so far been given little consideration when addressing a comprehensive transformation of the energy system and in particular the heat supply. Although these and other questions are addressed by various social science disciplines, they rarely reach the interdisciplinary dialogue and the design of political measures and instruments. (Arrobio/Sonetti 2021)

In the ZED Lighthouse, coherent concepts with highly innovative solutions have currently been developed, which address the challenges of the funding initiative and thus the goals of the Federal Republic of Germany and, with their implementation in the quarter, fulfil the lighthouse character for demonstrating the urban energy transition. This involves technical, social and economic elements whose intelligent interaction in a systemic-transdisciplinary approach leads to holistic innovations. To achieve the tightened climate targets, cities must maximise their contribution to the energy transition. The project "ZED (Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau's Energy Transition)" shows with its developed visionary future concept in the smallest urban unit – the quarter – that the goals of the energy transition (sufficiency, sector coupling, decarbonisation) can be implemented, especially in existing buildings, and thus proves the extremely high leverage effect of this approach. In addition, the development process of ZED is a prime example of how regional innovations can develop target-oriented approaches to solving social problems through the interaction of research and local knowledge from practice and society.

33.5 Specific Approaches of ZED with Reference to the Goals of the Energy Transition

In addition to the implementation of the energy transition in the quarter, the approach chosen in ZED manages to make the path towards it acceptable and sustainable for the environment and society. Especially for the implementation in existing buildings, resource efficiency is an important factor. On the one hand, the approach of the electric-thermal wide area synchronous grid in ZED creates a space-saving implementation, as no additional land consumption (sealing, etc.) occurs and thus there is no competition for space with other uses. Existing, previously unused roof surfaces (pitched roofs) are efficiently used for photovoltaics and solar heat, and decentralised storage facilities are accommodated in existing basement rooms of buildings. For new grid structures, routes of existing grids are used as a matter of priority, and the grids themselves are partially reused.

The security of supply, previously fossil-fuelled systems, is also guaranteed in the implementation of the new ZED overall system, through the expansion and inclusion of green district heating. This link between city-wide supply and local innovation means that district heating also becomes more efficient and its primary energy use decreases. The use, intelligent integration and linking of technologies already established on the market from photovoltaics, solar heat, district heating and storage, as well as the possibility of replacing the established system with the new one in sections, also lead to the preservation of supply security.

Despite the high degree of technical innovation of the ZED system, the self-imposed goal of maintaining neutrality of rent including heating as well as innovative operator models lead to a socially acceptable and thus affordable implementation. The use of renewable energies and the reduction of the residents' energy consumption also lead to the sustainable securing of affordable housing and the prevention of energy poverty.

In the project ZED, different building blocks, which are thought of in an integrative way, make a corresponding contribution to achieving the goals of the energy transition:

In ZED, several technical and social components, which are described in more detail in the following chapters, lead to the reduction of energy consumption (sufficiency). The plan is to reduce primary energy use by (at least) 84% compared to the current state in the sub-quarter:

As a central element of the developed electric-thermal wide area synchronous grid (see Chapter 33.6.1 of this article), a so-called smart thermal grid in interaction with an in-house development of a ubiquitous (information) infrastructure offers a new way of demand-driven heat supply. For the first time, supply and demand for heat/cooling from the flats are combined. In addition, the smart thermal grid offers the advantage of lower temperatures in the network due to its shorter supply sections. Thereby losses of distribution are minimised as well as by the demand-oriented "heat dispatch in package form". The information platform also manages as a "digital aid" to prevent major user misbehaviour and reduce user energy consumption through intelligent mechanisms. In the technology development (user-oriented) as well as in the later operation (user information/behaviour reflection), there is direct interaction between the system and the residents. Pre- and rebound effects are prevented. The year-round use of the electric-thermal wide area synchronous grid also ensures the establishment of a simple cooling function in the supply area in summer without additionally required infrastructures (energy-intensive air conditioning, etc.). The interface offered by the information platform for other value-added services created in the project and which is also available in the quarter, such as the ZED mobile station Marienthal (see Chapter 33.6.2 of this article), is as well the focus of the project and contributes to sufficiency (sharing instead of ownership) at neighbourhood level.

Sector coupling is implemented in the ZED project through the electric-thermal wide area synchronous grid. This directly couples heat and electricity and integrates other sectors such as mobility and information. In addition, the possibility of year-round sector coupling and the cooling function it enables he climate resilience of the quarter. The approach of the electric-thermal wide area synchronous grid also represents an open, flexible system that can also incorporate other (renewable) energy sources (wind power, hydrogen) in the future.

In the area of informational connection, via the developed information platform, to products and services in the quarter structures, participants are networked (energy, housing, health industry, mobility, etc.) and new joint operator models shall be enabled. (Leonhardt/Neumann/Kretz et al. 2019, Werner/Leonhardt/Höhne 2020, Franke/Kretz/Mager et al. 2020)

The gradual decarbonisation of the existing status quo (gas boiler) in the supply area is achieved in ZED by integrating various renewable energy producers. New primary energy sources in the local heating network of the supply area will be developed with photovoltaics and solar heat; in addition, the green district heating of the local supplier will be connected to the quarter. The mobility sector, integrated by sector coupling, also experiences a shift away from fossil energy sources in the form of charging infrastructure for electric vehicles and electric cars connected to the system. Decentralised thermal and electrical storage systems in the ZED project also manage to cushion the fluctuation of renewable energies, but also to store energy from the other sector (electricity in heat). In particular, energy in the form of heat can remain available for a longer period of time in the electric-thermal wide area synchronous grid.

33.6 Overall System and Implemented Parts

Based on the evaluation of the individual system approaches – conventional, centralised and decentralised – of the "individual sections of the quarter", the following overall system (33.6.1) was designed for the entire quarter Marienthal, taking into account the cross-cutting issues and overarching developments, which will be implemented for approx. 800 households and a school building in the quarter from mid-2022. Other individual overall system components and project approaches, such as the mobile station Marienthal (33.6.2) and the demonstration in the competence centre ubineum, have already been successfully implemented from 2020 and 2018 respectively.

33.6.1 Overall Technical System

Based on the work carried out in the project process and the parallel evaluation process of the individual concepts (centralised, decentralised) within the consortium, an electric-thermal wide area synchronous grid as shown in Figure 33.4 is to be implemented. This approach has enormous potential to achieve Germany's climate goals in urban areas and can act as a lighthouse for demonstrating the energy transition in

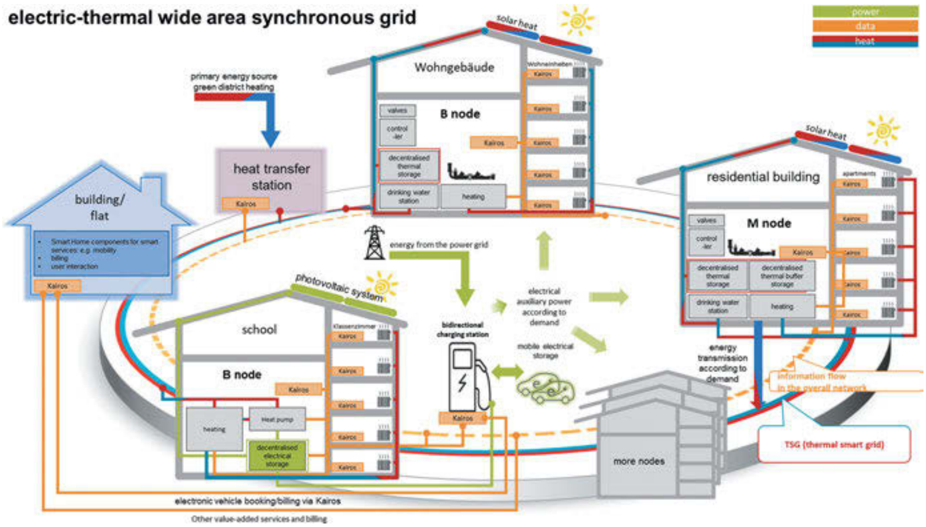

Figure 33.4: ZED energy system.

the quarter Zwickau Marienthal and beyond in the sense of the “Solar Construction/ Energy Efficient City” funding initiative.

33.6.2 Mobile Station Marienthal

The findings of the participatory interactions with stakeholders and residents were regularly incorporated into the conceptual work of the project team. Based on this procedure, target-oriented impulses for the project resulted for the conception of a mobility station and, beyond that, for the integration of the overall system. The aim was to ensure mobility for all residents of the quarter and thus to offer target group-specific environmentally friendly vehicles (electric scooters, electric bikes). In addition, the internal project communication and the participation workshops with stakeholders in the quarter led to the intention of not limiting the mobility station to offering mobility alone. The design of the station demonstrates to the citizens that projects of this kind should not be viewed one-dimensionally, but can set an example that other, integrative possibilities also exist. The mobility station serves not only as a provider of mobility, but also as a social meeting point in the quarter. By employing a “quarter pilot”, a contact person for residents is on site who helps people and informs about the project.

On 17 July 2020, the mobility station (Figure 33.5) opened for all residents of Zwickau-Marienthal. As a new building block for Zwickau’s mobility and transport transition at neighbourhood level, the station aroused curiosity about the services on offer, but also about the ZED project. (Ziegert/Höhne/Teich et al. 2021)

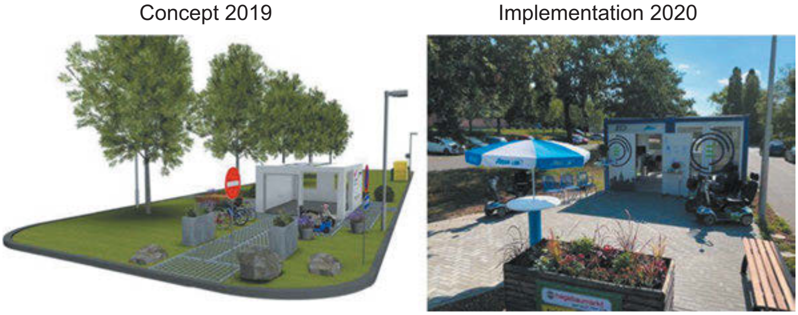

Figure 33.5: Concept and implementation of the mobile station "Marienthal mobil". (own illustration, own source).

33.6.3 Demonstration in the Context of the Project

ZED has aimed to demonstrate on the smallest scale level how the local, urban energy transition can be implemented. In a transdisciplinary approach, various ideas from different expert communities compete with each other (centralised, decentralised) to compare them with the conventional status quo in order to find out which innovative solutions can lead to sustainable implementation in practice. In the project, so far, the lighthouse character in technological development can be found especially in the exchange between research and relevant stakeholders from the housing industry, energy suppliers, service providers and residents, as well as in their interlocking (sector coupling). In this process, the project's charisma primarily reaches expert representatives in the individual sectors and, in the area of citizen participation, primarily interested parties. However, to ensure a successful implementation of the solutions in the area, a broad involvement of stakeholders and residents is indispensable, even if they are not among the experts of the energy transition. For this purpose, ZED is breaking new ground to take a holistic approach and look at cross-cutting issues such as mobility and the development of sustainable quarter structures in addition to the key issue of energy in conjunction with digitalisation. In this way, practical and sustainable concepts can be developed that address the everyday challenges of the quarter Zwickau Marienthal. By their very nature, participation processes are also innovation processes. They do not have a rigid sequence of phases, but many branches.

Experiences show that routine behaviour patterns have to be broken or complex contexts affected (e.g. energy supply, sustainable mobility), especially in the realisation of goals that go hand in hand with partly "hard" engineering changes. Communication with the right framing and an appropriate tone is necessary here. The ZED project has already shown in many ways that it can convey its message, the topics of the project and the energy transition in general, in suitable settings, including the tangible demonstration (Figure 33.6) (Leonhardt/Neumann/Schneider et al. 2018) of the planned energy system, albeit on a small laboratory scale at the competence centre ubineum.

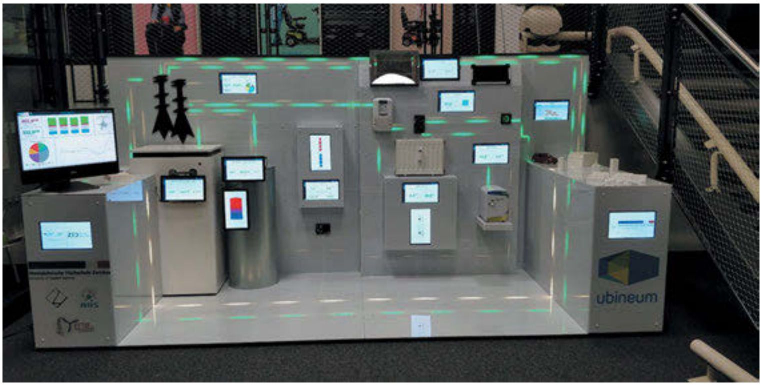

Figure 33.6: Developed demonstrator of the energy network in the ZED approach for transfer in the competence centre ubineum (own source).

33.7 Final Consideration

With its holistic transformation approach, the project ZED shows that the existing building sector can already become climate-neutral today, even without comprehensive renovation. With the help of technical solutions such as the developed wide area synchronous grid and digitalisation as a promoter of these and social innovations (value-added services, participation, etc.), other challenges facing society (demographic change, old-age poverty, etc.) can also be successfully overcome. The open interfaces (open data) in the system (energy, information, etc.) also promote the scalability and transferability of the approach. ZED can therefore be seen as a blueprint for a successful energy transition at neighbourhood level in an urban context. In order to achieve a sustainable effect as a lighthouse of the energy transition in the quarter itself, to tackle the transformation of the energy system, but also to take away the fear of it and to show that it can be implemented in an affordable, safe and environmentally friendly way. An actual implementation in the quarter is also necessary.

Network Partners ZED

ZED is embedded in the “Solar Construction/Energy Efficient City” funding initiative as one of six funded projects in Germany (Table 33.1).

Table 33.1: Network partners ZED.

1	SVZ	Stadtverwaltung Zwickau	Hauptmarkt 1	08056 Zwickau
2	WHZ/ WIW	Westsächsische Hochschule Zwickau – Fakultät Wirtschaftswissenschaften Professur für Vernetzte Systeme in der Betriebswirtschaft: Prof. Dr. rer. pol. habil. Dr.-Ing. Tobias Teich	Kornmarkt 1	08056 Zwickau
	WHZ/ VUT	Westsächsische Hochschule Zwickau – Institut für Energiemanagement: Professur für Gebäudeklimatechnik / Integrale Planung Prof. Dr.-Ing, Mario Reichel Professur für: Wärmetechnik/Computergestützte Planungsmethoden: Prof. Dr. rer. nat. Matthias Hoffmann	Kornmarkt 1	08056 Zwickau
	WHZ/ ET	Westsächsische Hochschule Zwickau – Fakultät Elektrotechnik: Professur für Energietechnik und Regenerative Energien: Prof. Dr.-Ing. Mirko Bodach	Kornmarkt 1	08056 Zwickau
3	TUC	Technische Universität Chemnitz- Fakultät für Maschinenbau: Institut für Mechanik und Thermodynamik Professur Technische Thermodynamik Prof. Dr.-Ing. habil. Thorsten Urbaneck	Reichenhainer Straße 70	09107 Chemnitz
4	LMU	Ludwig-Maximilians-Universität München - Sozialwissenschaftliche Fakultät Institut für Soziologie Prof. Dr. Bernhard Gill	Konradstr. 6	80801 München
5	ZEV	Zwickauer Energieversorgung GmbH	Bahnhofstr. 4	08056 Zwickau
6	GGZ	Gebäude und Grundstücksgesellschaft Zwickau mbH	Gewandhausstraße 7	08056 Zwickau
7	GIIZ	Gesellschaft für Intelligente Infrastruktur Zwickau mbH	Uhdestraße 25	08056 Zwickau
8	JUH	Johanniter-Unfall-Hilfe e.V. Regionalverband Zwickau/Vogtland	Uferstraße 31	08412 Werdau
9	ALI	Alippi GmbH	Leipziger Straße 160	08058 Zwickau

Table 33.1 (continued)

10	BC	Bauconzept Planungsgesellschaft mbH	Bachgasse 2	09350 Lichtenstein/Sa.
11	SAM	Samson AG	Weißmüllerstraße 3	60314 Frankfurt am Main
12	ASD	Autoservice Demmler	Kirchberger Str. 55	08112 Wilkau Haßlau
13	SEN	Senertec Sachsen	Karlsbader Str. 65	08359 Breitenbrunn

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Tobias Härtel, Mario Reichel, Martin Schwind

34 Thermal Smart Grid for Decentralised Heat Supply in the Quarter

Summary: The current orientation of the energy supply system in Germany towards fossil fuels requires a fundamental conversion to renewable energy sources and a restructuring of existing heat supply systems due to sharply rising prices and an increasing lack of resources. The focus of the present energy supply concept for a residential area in the quarter Marienthal, Zwickau and the adjacent school “Schule am Windberg” is the transformation of an existing conventional local heating network into a Thermal Smart Grid using sector coupling, renewable energy sources and the bidirectional dispatch of energy packages. The developed contexts can also be applied to other residential areas and show exemplary innovative ways for the efficient ecological design and operation of future-oriented local heating systems.

34.1 The Path to a Future-Oriented Decentralised Energy Supply System

Currently, the global energy supply systems are still very strongly oriented towards the use of fossil fuels. In the future, a shortage and an increase of prices of these energy sources are expected. For this reason, primary energy demand must be reduced and substitution by renewable energy sources is getting more and more important. Due to their properties, decentralised integration into existing energy supply systems and decentralised energy storage are required.

34.1.1 Problems of Current Energy Supplies

To counter the man-made contribution to global warming, worldwide efforts must be made to reduce CO_2 emissions and other heat-absorbing substances in the atmosphere. European climate targets call for net zero emissions of greenhouse gases by 2050. (EU 2021) Based on the European climate targets, the Climate Protection Plan 2050 of the Federal Republic of Germany stipulates a reduction of at least 55% by 2030 as a medium-term interim target and almost complete greenhouse gas neutrality by 2050. (BMUV 2019) This means that the use of fossil fuels must be massively substituted. Decarbonisation goes hand in hand with decentralisation, especially of electri-

Tobias Härtel, Mario Reichel, Martin Schwind, Westsächsische Hochschule Zwickau

https://doi.org/10.1515/9783110777567-034

cal power generation. Quarter solutions as a component of virtual power plants primarily secure local innovative electrical energy generation and use through electrical-thermal compound system. Temporary surpluses or deficits are compensated for by storage solutions and intelligent networking strategies.

Furthermore, operators of energy supply systems must achieve their economic risk by reducing their dependence on energy imports as well as unpredictable price developments. Finally, end consumers must be guaranteed a high level of supply security at affordable prices in the long term.

In this context, the quarter solution presented in this article with a decentralised thermal-electrical compound system in combination with an intelligent heat supply system that is effective down to the user level represents a technical solution that meets all requirements and demands and can be seen as a future-oriented decentralised energy supply system. Compared to traditional heat supply concepts, this solution offers a considerable reduction in primary energy demand and the associated greenhouse gas emissions. Furthermore, the heat losses and the electrical transport energy demand in the heat distribution system are reduced and it enables the decentralised and grid-serving integration and efficiency increase of renewable energy sources.

34.1.2 The Thermal Smart Grid for Decentralised Energy Supply

The transport and distribution of the heat transfer medium is a key issue in the operation of a heating system, especially in the scale of a local heating system in residential, commercial, industrial and mixed industrial/residential areas. Essentially, the concept of a Thermal Smart Grid (TSG) represents a complex system of communicative networking, generic control of energy generators, storage units and thermal consumers. The concept of a Thermal Smart Grid offers the possibility to make surplus heating and cooling energy, which is released unused into the environment, available to other network users connected to the supply network. An energetic redistribution of the heating and cooling energy takes place between the network participants, whereby ecological and economic advantages are achieved. The redistribution reduces the energy demand, which in turn reduces primary energy consumption and CO_2 emissions. With the thermal smart grid, all conceivable producers and consumers can exchange energy with each other in a common network (cf. Figure 34.1).

The Thermal Smart Grid is an innovative decentralised heat distribution system in which energy distribution is realised through the targeted sending of energy packages. A decentralised energy storage unit is installed at each network subscriber, which serves to receive and deliver energy packages to be received and sent. This enables permanent supply security for the grid subscriber until the next delivery and the integration of renewable energy sources. Energy packages can be sent bidirectionally between the grid participants by the grid participant reporting a demand and acting as a consumer (sink) or by the grid participant having surpluses from its own energy source

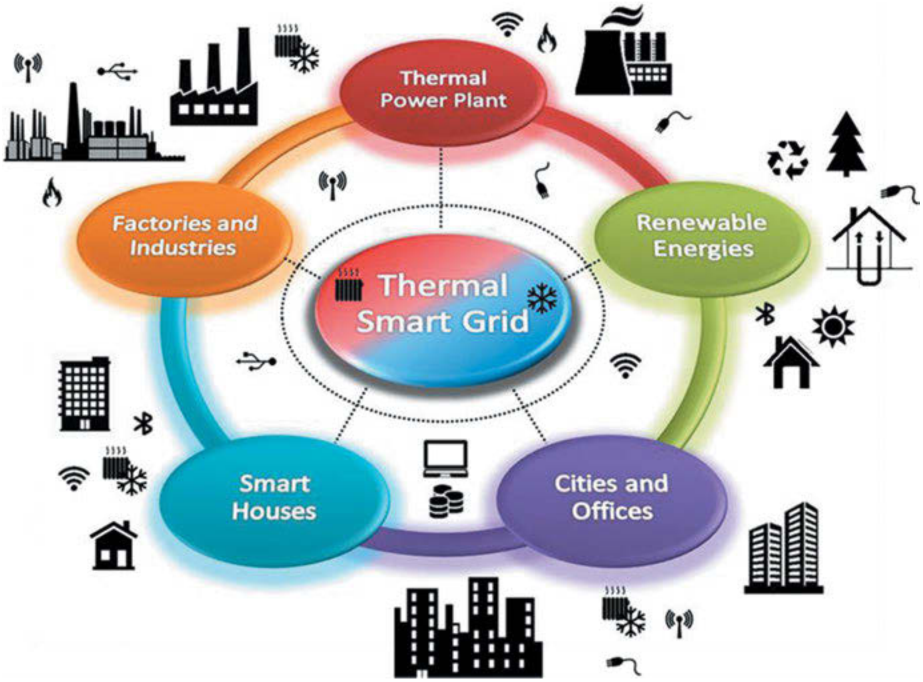

Figure 34.1: Basic concept of a Thermal Smart Grid (Hoffmann/Härtel/Blumhagen et al. 2017).

and thus acting as a producer (source). The surpluses will be provided to the overall grid and thus to other grid participants. Compared to a conventional local heating network (LHN), in which a permanent circulation of the supply medium takes place in the supply lines and is accompanied by a constant supply of energy, the Thermal Smart Grid reduces energy losses and allows for a flexible and individualised energy supply.

The function of the Thermal Smart Grid requires a hierarchical structure and an informational network for demand and order processing for bidirectional energy supply. Figure 34.2 shows the network structure of a Thermal Smart Grid. Network nodes are necessary as central units for the distribution of heat or cold. Basically, these network nodes are differentiated into multivalent nodes (M-nodes) and bivalent nodes (B-nodes). A B-node corresponds to a sink (consumer) or a source (producer) that can bidirectionally draw or emit thermal energy. It represents the smallest unit in a Thermal Smart Grid. It is installed at every network subscriber, unless an M-node is used, and serves, for example, to supply a residential, industrial, cultural or educational building. Furthermore, the B-node is equipped with connections for the integration of regenerative energies. At this point, decentralised energy emitters can be integrated, but also surplus heat from cooling systems from companies or other facilities can be brought in and thus made available to other network participants. The M-node is the superordinate distribution device to the B-nodes and takes over the coordinative tasks in the network. The exchange of thermal energy in the form of energy packets takes place bidirectionally between B- and M-nodes and between two M-nodes of different grid clusters. In the Thermal Smart Grid, the lines can no longer be classically differentiated into flow and return due to the bidirectional supply, which is why a division into a HIGH network area with higher temperature and a LOW network area with lower temperature takes place. The M-node combines the two network areas and forms a spatially centred distribution unit.

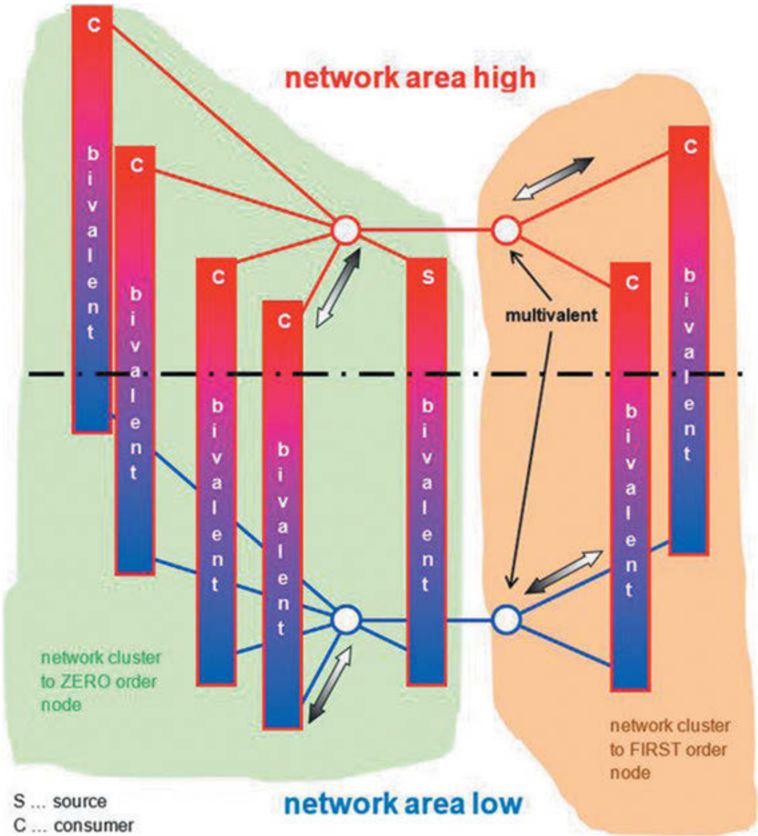

Figure 34.2: Network structure of a Thermal Smart Grid (Hoffmann/Häselbarth/Theil 2016).

The conversion of an existing supply network to a Thermal Smart Grid can be done step by step during ongoing operation. First, the information and communication technology structures must be set up and tested. The node stations for M-nodes and B-nodes can be installed and initially run in conventional operation with decentralised pumps. Once all B-nodes connected to an M–node are equipped, the Thermal Smart Grid software is activated and Thermal Smart Grid operation begins.

The concept development of the "Thermal Smart Grid" for decentralised energy supply has already been started in previous projects. In a first development phase, the grid node station was developed as a pilot plant in static operation at the "Institute of Energy and Transport Engineering" at the University of Applied Sciences Zwickau ("Development of grid node stations for intelligent local heating grids" (2013–2015), (Hoffmann/Häselbarth/Theil 2016)). With the second development phase, this system could be further developed and tested in practical building operation within a real heating and cooling system of the Ubineum Zwickau ("Demographic energy–balanced framework for sustainable urban environments" (2016–2018), (Härtel 2018)). In these two development phases, the networking of information flows, the hydraulic behaviour at the grid node station as well as economic and operational interrelationships have been experimentally investigated. The topic was further presented in (Hoffmann/Härtel/Blumhagen et al. 2017) and published in (Härtel/Reichel 2020). The Thermal Smart Grid is currently in a third development phase and has been further developed in the joint project "Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau's Energy Transition" (ZED) for implementation in a real laboratory as a thermal-electrical compound system.

34.2 Presentation of the Existing Quarter as a Real Laboratory

For the conceptual design of an innovative heat supply as a thermal-electrical compound system, the current state of the quarter must first be determined. This includes information on the structure, ownership, building condition, existing heat supply systems and the like, which must be gathered and documented in extensive research and on-site inspections. The documentation of the results and the data collection was carried out in individual drawings and diagrams, project-specific databases and verbal descriptions. Furthermore, an energetic examination of the actual condition is necessary for the determination of savings potentials. All the documents produced served as a sound basis for subsequent simulations and calculations in Chapters 34.3 and 34.4.

34.2.1 Quarter Structure, Building Condition and Heat Supply through the Existing Local Heating Network

The supply area selected as the real laboratory is a homogeneous residential area with 21 buildings, including 720 residential units, adjoined to the north by an educational complex with a school and gym. There is currently one conventional local heating network in the real laboratory, which supplies heat to the properties of various owners. Figure 34.3 shows the structure of the supply area in terms of area division and ownership structure. A total of three spatial areas are distinguished. The area of the school / gym, which is owned by the municipality of the city Zwickau, and the area of the residential buildings, which comprises two development stages G1 and G2. The red frame in the G1 area contains the properties owned by the project partner Gebäude- und Grundstücksgesellschaft Zwickau mbH (GGZ). These and other owners interested in the project form the area G1 (yellow frame). All buildings of G1 together with other buildings of other owners form the area G2 (blue frame), which is supplied by the currently existing conventional local heating network.

Figure 34.3: Structure of the real laboratory under consideration (Leichsenring 2018).

As Figure 34.3 shows, a total of three heating centres with gas condensing boilers are integrated in the conventional local heating network, two of which are owned by GGZ. A central drinking water heating system is also installed in each building. Only the gas condensing boilers are used to generate heat. Documents on the construction of the conventional local heating network, which is currently operated by a contractor, were not available.

Due to insufficient information on the construction of the local heating network inside and outside the buildings, a comprehensive survey and documentation of the pipe routes in the buildings was carried out on site. In addition to heat generators, heat storage tanks and pipelines, all fittings, transfer and measuring points, pipe dimensions and the insulation condition were documented. The documentation for this was done in several route and hydraulic diagrams. In addition, the installed heat meters (HM) were read out and evaluated retrospectively. The actual heat consumption was compared with the energy performance certificates. These give an insight into the actual conditions of the building heating and hot water preparation.

To determine the condition of the building, research was necessary in the archives of the owner GGZ. Building plans of the construction and other documents could provide information about the existing building standard and about renovation measures. The buildings belonging to GGZ in the research area were constructed according to the Q20, Q25 and Q225 building standards of the former GDR. The buildings date from the first development phase of industrial housing construction of the time, they were built in 1959 / 1960. The apartment blocks always have 4 residential floors with 2 or rarely 3 residential units per floor. The researched data were the basis for further calculations and simulations. At the end of the 1990s, the owner implemented extensive renovations to optimise the thermal properties of the building. These measures included insulation of the exterior facade as an external thermal insulation system, insulation of the roof area and the basement ceiling. The replacement of windows and doors should also be listed here. Around the year 2000, the GGZ buildings and surrounding buildings were connected to the local heating network. The energy performance certificates were available for further processing.

After extensive research and the inspection of building documents, the building type of the school “Schule am Windberg” could be clearly determined with the GDR building standard type TS 66 and thus properties of the building envelope could be taken. Windows and doors were renewed in the 1990s. The “Schule am Windberg” is scheduled for a core refurbishment in the coming years in conjunction with an energetic refurbishment.

Furthermore, an evaluation and investigation of the available space in the basement could be carried out. The background was the clarification of installation possibilities for the construction of perspective network nodes. After the basement rooms had been surveyed, they could be divided into three types depending on their structural room geometry. Based on the intended typification, the space planning and cost estimation required in the further course of the project could be implemented.

34.2.2 Energy Analysis of the Current State in the Residential Area

The energy analysis of the actual state was developed on the basis of a comprehensive energy balance and it was possible to determine the primary energy demand as well as the CO_2 emissions for the entire system in the area G2. This requires a balance of the entire energy flow chain from the required primary energy to the useful energy demand of the buildings in the supply area, including all thermal losses.

Figure 34.4 shows the actual state of the energy and CO_2 balances in the entire area in the form of a Sankey diagram. Processing the actual consumption data provided information on the energy demand for residential area G2. An annual heat demand of 4097 MWh/a can be assumed, which is provided by the existing gas condensing boilers in the heating centres. Based on the existing conventional distribution network, a transport loss of 12.3% is to be expected. The school and gym have a combined heat demand of 1303 MWh/a (source: energy performance certificate). After deduction of transport losses, 1862 MWh/a are used for generation by the existing boilers. To cover the energy demand in the entire area G2, including the school, 9407 MWh/a of primary energy must be used. Therefore, 20 MWh are required to cover electrical energy and auxiliary energy. Overall, 3987 MWh/a are to be seen as energy losses and a total CO_2 emission of 1728 t/a was determined. For the heating network, an electrical energy demand of 11 MWh/a can be assumed.

34.3 Concept Development of the Innovative Heat Supply in the Quarter as a Thermal-Electrical Compound System

Due to the ownership and quarter structure described in Chapter 34.2.1, several stakeholders are involved in the development of the supply concept within the framework of the joint project ZED. For the concept as a thermal-electrical compound system, the scientific partners University of Applied Sciences Zwickau and Chemnitz University of Technology (TUC) developed different supply options together with the practice partners Zwickauer Energieversorgung, GGZ and the municipality of Zwickau. These options were investigated and assessed in an energy network simulation regarding the mode of operation as a local heating network or as a Thermal Smart Grid and in a balance sheet concerning CO_2 emissions and primary energy use. Finally, the investigated options were assessed in an evaluation and decision-making process within the stakeholders. As a result, the decision was made to consider and further develop one option until it was ready for implementation.

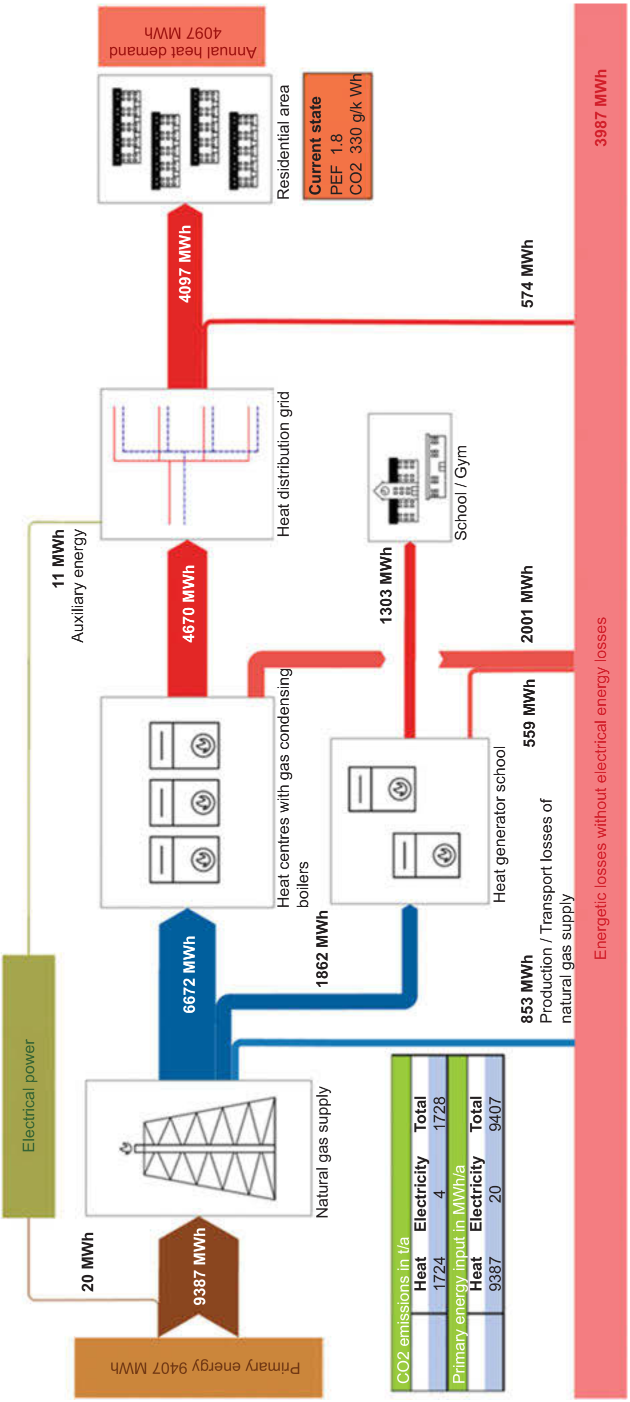

Figure 34.4: Energy analysis of the current state in the quarter.

34.3.1 Concept Description and Potential Supply Options

The concept of a heat supply as a thermal-electrical compound system provides the coupling of heat and electricity sectors in one system. For this purpose, the combination of a decentralised and a centralised heat supply approach was investigated with the stakeholders of the working group "thermal-electrical compound system". For this purpose, the overall concept was divided into the areas of energy centre (EC; centralised approach) and supply network (decentralised approach). The energy centre is responsible for the heat supply and for the transfer to the supply network. This topic has been scientifically investigated by the TUC in (Nefodov/Xiao/Richter et al. 2020) and (Xiao/Nefodov/Urbaneck 2019) and includes the efficient use of large-scale heat pumps using a return cooling system of the municipal energy supplier in combination with a large-scale heat storage system to supply heat to the quarter throughout the year. Furthermore, the integration of a photovoltaic system to operate the heat pumps is part of the centralised approach. In the supply network, the decentralised approach is pursued as a Thermal Smart Grid, as explained in section 34.4.4. For this purpose, the network participants (residential blocks) are equipped with decentralised heat storage units and decentralised energy generators in form of a solar thermal system. In the supply network, the decentralised approach in conjunction with the energy package dispatch reduces the thermal network losses as well as the transport energy demand due to the discontinuous mode of operation. In addition, a better utilisation of the solar systems can be achieved by exchanging energy between the grid participants. The energy centre compensates for the deficit of heat that cannot be generated and shifted in the Thermal Smart Grid. The combination of centralised and decentralised approaches has advantages for both approaches. It reduces the heat demand and results in a saving compared to a centralised supply with a conventional heat supply network.

For the energy network simulation, the overall concept of the thermal-electrical compound system including the combination of the two supply approaches was subdivided into a total of five supply options. The subdivision was based on the use of centralised and decentralised supply as well as on the mode of operation as a conventional local heating network or as a Thermal Smart Grid, as shown in Table 34.1. Additionally, the supply network was divided into three network clusters in order to map the characteristic Thermal Smart Grid hierarchy and the different expansion stages.

Option V0 corresponds to the supply network in its current state with the operating mode as conventional local heating network and the three heat generation plants, as described in Section 34.2.1. This option serves as a reference model for the evaluation of plan variants 1 to 4. Option V4 was created as an additional alternative and is only used if the course of the project would show that options V1, V2 and V3 cannot be implemented together in one system. In options V1, V2 and V3, the supply network was also subdivided according to the size of the area and the size of the solar thermal systems. Each alternative was again divided into two area expansion stages and three

Table 34.1: Supply options in the concept development.

Option	Description
V0	Local heating network in the current state, as described in Chapter 34.1
V1	combination of centralised and decentralised approach energy centre + supply network, all three network clusters as thermal social grid
V2	combination of centralised and decentralised approach energy centre + supply network, two network clusters as Thermal Smart Grid and one network cluster as conventional local heating network
V3	central approach and conventional supply network energy centre + supply network, all three network clusters as conventional local heating network
V4	separate consideration of centralised and decentralised approach sub-network with energy centre + supply network as conventional local heating network sub-network with decentralised producers + supply network as Thermal Smart Grid

solar expansion stages. For the area expansion stages (G1 and G2), an approach based on ownership and the spatial grouping of the properties was chosen. The solar expansion stages were defined according to a percentage occupancy rate of the available roof areas (0%S, 5%S and 10%S). This results in 18 different options, which are designated with the nomenclature area – option – solar roof area occupancy (example G2-V1-10%S).

34.3.2 Energy Network Simulation and Assessment of the Supply Options

The supply options described in Chapter 34.3.1 were subjected to an energetic grid simulation. The energy analysis of option V0 is explained as a reference option in Section 34.2.2. The piping system for options V1, V2 and V3 was redesigned and mapped in the simulator. For this purpose, a routing scheme was created for each alternative.

An extensive dynamic heat demand and network operation simulation was implemented for the three variants including their sub-variants in terms of area and solar expansion stage. After the statistical evaluation of the state variables of the demand processes, the solar heat gains and the heat transfer, the annual gross, net heat and auxiliary energy demands (electrical energy for pump operation) were determined for 0%, 5% and 10% roof area occupancy with solar thermal systems for the areas G1 and G2. The basis for this was the available energy performance certificates and the floor plans of the buildings as well as the assessed building condition. The results were exchanged with the partner TUC for the adaptation and interface definition of the supply by the energy centre.

A significant result of the Thermal Smart Grid approach with the discontinuous mode of operation (energy package dispatch) is the high savings potential in electrical energy for network pump operation and a considerable reduction in network heat losses. As an example, the demand for electrical energy for network pump operation is reduced by more than 70% between the two options V3 and V1 in area G2. Compared to a conventional local heating network, in the Thermal Smart Grid heat is sent discontinuously as an energy package between the individual network participants. When the transport process is completed, the supply lines are run cold, the heat storage is then fully charged and supplies the network subscriber until the next energy package arrives. By using these Thermal Smart Grid transport processes, the network heat losses between the options V3 and V1 in area G2 can be reduced by 40%. (Härtel/Reichel 2020)

Furthermore, the network simulation enables the simulation of the heat package delivery and the simulations of the operation as Thermal Smart Grid. This is based on the pipe network dimensions and the hydraulic pressure loss calculation in all pipe sections. The Thermal Smart Grid process was mapped and thermally and energetically replicated in the simulator. The temporal utilisation of the pipe sections between the nodes and the load change processes of the M-nodes and the B-nodes were simulated for the different supply options. With the help of this simulation, overloads or collisions in the heat package supply can be determined. In the network, heat packages with a temperature spread of 30 K and a volume of 1 m^3 are conveyed. The decentralised buffer storage tanks in the blocks have a volume of 0.4 m^3 multiplied by the number of staircases in the residential block. The conveying speed on the pipes is reduced to 50% of the maximum design speed. As a result, it can be stated that the heat transfer medium conveyance with the Thermal Smart Grid process is only 11% of the available time compared to the conventional local heating network.

The supply network simulation in all sub-variants was then extended to include the overall concept and the thermal-electrical compound system with a centralised and decentralised approach. The aim is to calculate and balance the CO_2 emissions and primary energy use in the entire quarter and to determine the savings potential compared to the current state. For this purpose, the results of the network simulation were combined with the results of the energy centre investigated by the TUC. The balancing concerns the entire energy flow chain from the required primary energy to the useful energy demand of the buildings in the supply area, including all solar gains and all thermal losses. Overall, the energy balances were prepared for all three options (V1, V2, V3) including their sub-variants with regard to the solar expansion stage for the area G2. The subdivision of the area expansion stages G1 was not balanced, as the decision was made to consider the entire area G2. Furthermore, the energy flow chains of selected supply options were shown in a Sankey diagram. (Härtel/Reichel 2020) As a result, it can be stated that the overall concept leads to a considerable reduction in primary energy and CO_2 emissions. Figure 34.5 shows the comparison between two selected options G2-V1-10%S and G2-V2-5%S Kairos and the current situation. The clear reduction of primary energy use by approx. 65% and CO_2 emissions by approx. 45% through the overall concept as a thermal-electrical compound system is recognisable.

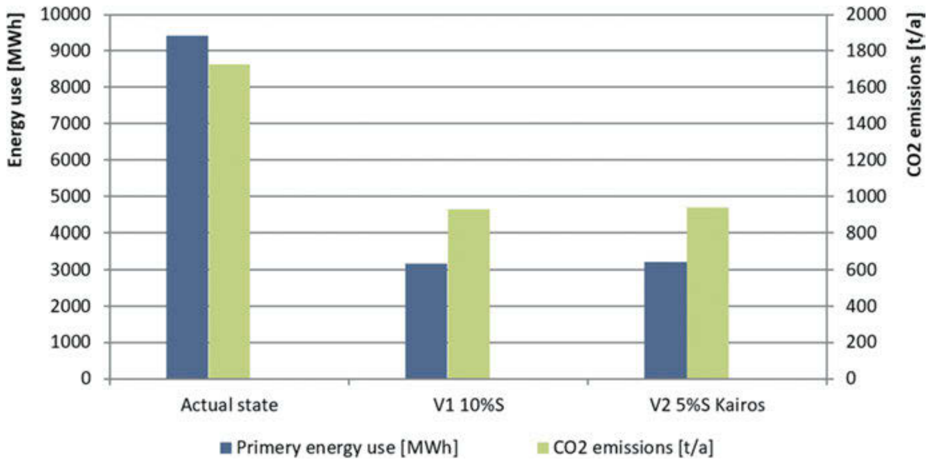

Figure 34.5: Comparison in terms of primary energy use and CO_2 emissions of selected options.

Kairos is a software developed by the University of Applied Sciences Zwickau, Faculty of Economics, which serves to optimise various system components. This system has already been published in (Kretz 2021) and (Leonhardt/Neumann/Teich 2018) and described in more detail in the chapter "Informationstechnische Vernetzung im Quartier und im Gebäude – Kairos". It provides an effective and direct coupling and linking level, especially in improving system operation, through the collection, storage and processing of data from all parts of the system as well as in the flats, e.g. through smart home technology. The software aggregates and evaluates information from the individual residential units, for example, regarding temperature, energy consumption, time of use and external weather influences. In this way, a future forecast can be made, which is used as an input variable in the demand-oriented supply and planning of energy packages. In the balancing of the options, the effect is taken into account by the software via an additional reduction in the heat demand of all buildings. In the case of the G2-V2-5%S Kairos option, this reduction is only approx. 3%, as only four of the 21 buildings are initially equipped with Kairos as a test. If the buildings are fully equipped, a saving of approx. 15% can be assumed.

34.3.3 Selection and Decision of the Perfect Heat Supply Option for Implementation in the Quarter

As described in Section 34.3.2, a simulator was developed, which is an important tool for modelling and evaluating different supply options. The results obtained provide a sound basis for the economic and energetic evaluation of the supply options and enable the decision-making process for an optimal implementation variant as a thermal-electrical compound system.

In the decision-making process, the supply option G2-V2-5%S, which will be further developed until it is ready for implementation, was selected. In detail, this means a combination of a centralised and decentralised approach and an expansion stage for the supply network to the entire area G2 with 5% roof area occupancy by solar thermal systems. In the supply grid, two grid clusters are operated as Thermal Smart Grid and one grid cluster as conventional local heating network. Since for various reasons it is not possible to integrate the energy centre investigated by the TUC, it was replaced by a central transfer station. The thermal-electrical compound system is realised at the “Schule am Windberg” by linking a photovoltaic system, a heat pump for heating and cooling and an electrical storage system. The following Chapter 34.4 explains the overall concept of the thermal-electrical compound system for implementation in the real laboratory.

34.4 Overall Concept of the Thermal-Electrical Compound System for Implementation in the Real Laboratory as a Result of Concept Development

The overall concept of the thermal-electrical compound system is implemented in the supply option G2-V2-5%S, as explained in Chapter 34.3. This option was developed to implementation readiness and is described in the following. This chapter will deal specifically with the concept for the residential area in terms of heat supply, while also explaining the issue of supplying the school and the transfer station between the primary and secondary networks as part of the overall concept. The focus is on the integration of a Thermal Smart Grid with regard to system and control technology. Furthermore, the structure of the supply area and the energy balance of the overall concept are described.

34.4.1 Structuring the Supply Area

The supply area is subdivided into several areas for the development of the overall concept with a sustainable and intelligent heat supply concept in the form of a thermal-electrical compound system. In terms of content, the concept includes the sub-areas of the residential area, the school site and the technical building. A thermal energy connection to the district heating network of the regional energy supplier is realised via the technical building. A heat transfer and network separation station between the primary and secondary networks is located in the technical building, which is responsible for supplying the entire secondary network. From this central point, the gym, the school and the residential area are connected in conventional mode. The residential area is planned for a partial conversion to a Thermal Smart Grid and the school is considered in a separate heating and cooling supply concept.

The network area is divided into four clusters (Z0 to Z4) for the application of the Thermal Smart Grid, the division of the network structure and the definition of the operating modes. The clusters Z1 and Z2 are operated as Thermal Smart Grid. Each of the clusters is connected to the heat transfer station (K21) with conventional operation through an M-node. At the M-node, the bidirectional supply of the downstream B-nodes with the operating mode as Thermal Smart Grid begins by sending energy packages. Network cluster Z3 is supplied via conventional house connection stations in conventional mode of operation. The school (Z0) is supplied via the secondary network. For this purpose, it is connected as a network subscriber (K0) to the conventional heat supply of the heat transfer station (K21). It has the functional scope of an M-node and thus the operating mode as a Thermal Smart Grid. The network character is not given because there are no downstream B-nodes. Figure 34.6 shows the clusters and all conceptually integrated nodes.

The solar thermal systems are shown in Figure 34.6 with yellow outlined dots and are only planned for selected buildings. In order to realise an electrical-thermal compound system, the concept provides for the integration of photovoltaic surfaces, which are to be installed on the roof of the school.

34.4.2 Transfer Station in the Technical Building

The connection of the supply area to the primary grid takes place in the technical building on the school's property. The technical building, as shown in Figure 34.7, is responsible for supplying the entire secondary network and serves as a heat transfer and network separation station. As already mentioned, the gym, the school and the residential area are connected to the technical building in conventional operation as conventional local heating.

The technical building is equipped with the following plant technology. The transfer of district heating to the secondary network is carried out by a heat transfer station. Furthermore, a hydraulic separator, a central pump system and a dynamic pressure maintenance system with automatic replenishment from the district heating network are provided. The technical building is also equipped with extensive measurement, control and regulation technology (MCR), heat meters and server technology.

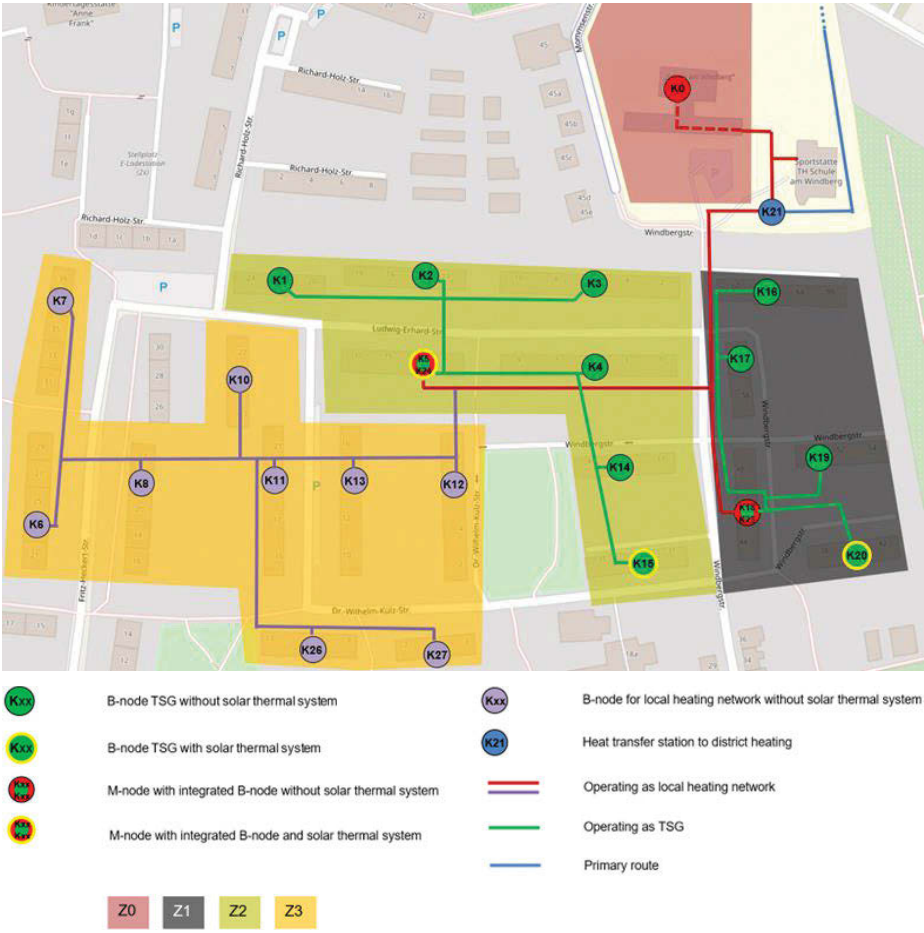

Figure 34.6: Structuring of the supply area into clusters and mapping all nodes (Härtel/Reichel/Hoffmann et al. 2022, FOSSGIS e. V. 2021).

34.4.3 Heating and Cooling Supply Concept for the School

The school "Schule am Windberg" is intented for a core renovation in conjunction with an energetic renovation of the building envelope. In this way, an innovative supply structure can be implemented through new technical building equipment. The concept was described in detail in (Härtel/Reichel/Hoffmann et al. 2022). As part of the project ZED, an intelligent and sustainable heating and cooling supply concept was developed. The concept provides for sector coupling in a thermal-electrical compound system. For this purpose, a brine/water heat pump in heating and cooling mode is integrated as a central element with the linking of various heat sources and sinks for

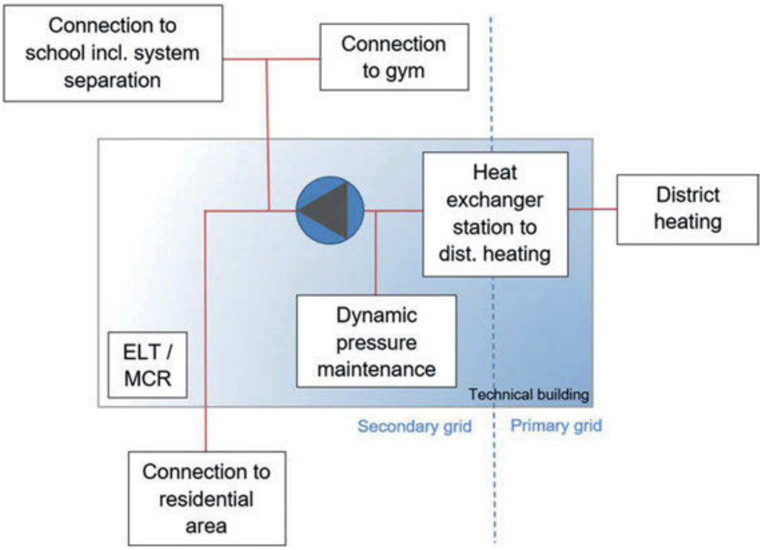

Figure 34.7: Transfer station between primary and secondary network in the technical building (Härtel/Reichel/Hoffmann et al. 2022).

air conditioning the school. The photovoltaic system installed on the building supports the year-round operation of the brine/water heat pump in heating and cooling mode, linking the electricity, heating and cooling sectors.

The main objectives are to reduce primary energy demand and CO_2 emissions by maximising the use of renewable energy at the point of generation. For this purpose, the conversion of photovoltaic and environmental energy into useful thermal energy for heating and cooling purposes is maximised and the feed-in of surplus photovoltaic energy into the electricity grid is minimised, resulting in a grid-serving integration of the photovoltaic system.

The linking of the photovoltaic system and brine/water heat pump in heating and cooling mode and the combination of the different energy sources are shown systematically in Figure 34.8. On the evaporator side, the brine/water heat pump in heating and cooling mode is connected to three different energy sources. The energy sources are the table cooler for drawing environmental energy, the cold store for cooling the school building and the return cooling for extracting heat from the secondary network. As a heat sink with the function as a Thermal Smart Grid node "school", the brine/water heat pump in heating and cooling mode is connected on the condenser side to the heat storage tank, which is primarily used to heat the school. The connection to the secondary network is implemented by a heat transfer station, which enables the coupling and decoupling of heat depending on demand or surplus. The brine/water heat pump in heating and cooling mode is supplied with auxiliary energy by the photovoltaic system in conjunction with the electricity storage system or by the electricity grid using emission-free power.

Complex control algorithms are required for the intelligent control and regulation of the individual system components for heating and cooling supply, an overview of which is given in the following. In summer operation and occasionally also in the transitional period, the provision of cooling for the air conditioning of a single or several rooms is required by the brine/water heat pump in heating and cooling mode. Heat is provided for heating the building in winter and sometimes in the transition months. When there is a surplus of heat in the building, it is extracted by raising the return temperature in the secondary network. Heat can be supplied indirectly as return cooling in connection with the brine/water heat pump in heating and cooling mode or during load peaks when the maximum heat output of the brine/water heat pump in heating and cooling mode is reached. Surplus electricity that is not used for heating and cooling purposes is used to generate heat by utilising environmental energy from the ambient air. The heat is extracted in this case in the form of a return temperature increase into the secondary grid. The storage of electrical energy occurs when further photovoltaic surpluses cannot be converted into thermal energy and decoupled. This leads to a grid-serving integration of the photovoltaic system, as electricity surpluses are converted or stored. If there is a need for cooling and there is a shortage of electric-

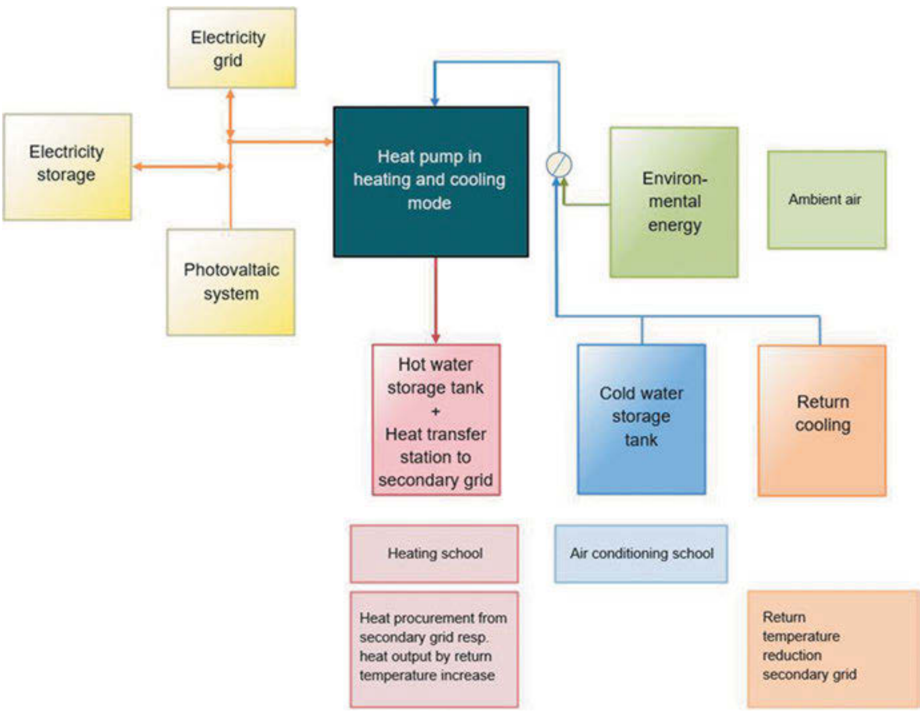

Figure 34.8: Systematic description of the school's heating and cooling supply concept (Härtel/Reichel/Hoffmann et al. 2022).

ity, emission-free electricity is drawn from the grid, which means that other renewable energies (e.g. wind power plants) are used. Further information on the heating and cooling supply concept of the school “Schule am Windberg” with regard to design, system technology, control and energy simulation has been published in detail in (Nefodov/Xiao/Richter et al. 2020) and (Xiao/Nefodov/Urbaneck 2019).

34.4.4 System Technology for the Operation of the Residential Area as a Thermal Smart Grid

Two types of nodes are used as main components for the operation of the Thermal Smart Grid. Heating and hot water production in the building is provided by the B-node. The heat transport to the subordinate B-nodes is implemented by the M-node. In addition, this node takes over the coordinative task of energy distribution. A B-node is the smallest unit in a Thermal Smart Grid. It is installed at every network subscriber, unless an M-node is used, and serves to supply the residential building. The hydraulic structure of a Thermal Smart Grid B-node, including the solar thermal system, is shown in Figure 34.9.

It is equipped with a thermal multifunctional storage tank. Through the intermediate storage of energy, it can minimise media movements in the heating network, relieve the network and thus ensure security of supply. Furthermore, the B-node is equipped with connections for supplying downstream consumer circuits for heating and hot water as well as with a connection for a solar thermal system, which is integrated into the system via the decentralised storage tank. They primarily serve to supply heat to the building in which they are installed and make the surplus heat available to the Thermal Smart Grid as decentralised emitters and thus as decentralised heat sources. The storage tank has several temperature sensors distributed over the height to assess the storage tank charging status. The heat meters are used to record incoming and outgoing energy quantities. In Figure 34.6, the B-nodes for the Thermal Smart Grid conversion are marked in green.

An M-node represents the superordinate distribution unit to the B-node and is marked with green-red circles in Figure 34.6. This coordinates the demands and corresponding possibilities of energy distribution between the subordinate B-nodes and exchanges information with M-nodes of other grid clusters in order to organise energy supplies. Figure 34.10 shows the hydraulic structure of an M-node with integrated solar thermal system.

Hydraulically, the M-node is similar to a B-node, but an M-node has one or more additional buffer tanks to increase the storage volume and thus the storage capacity. It also has a pump switching station consisting of a line pump for transporting the energy packages and several switching ball valves for reversing the flow direction. In this way, energy packages can be sent to supply heat or redistribute excess solar heat. Each M-node is connected to the main line, which provides the supply from the side

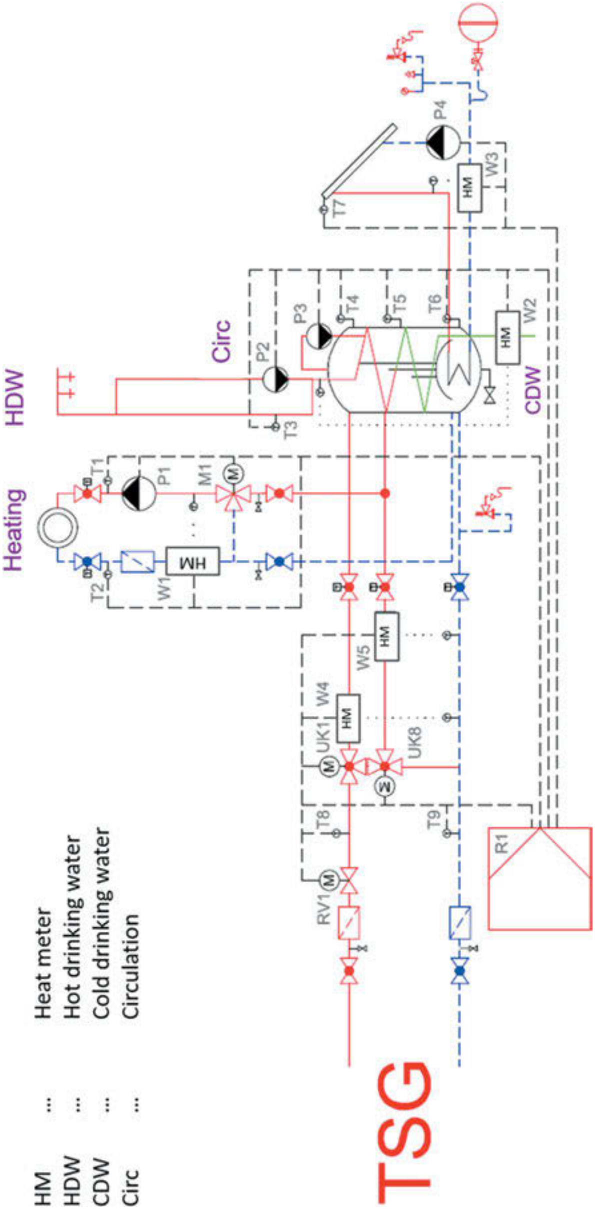

Figure 34.9: Hydraulic structure of a Thermal Smart Grid B-node with integrated solar thermal system.

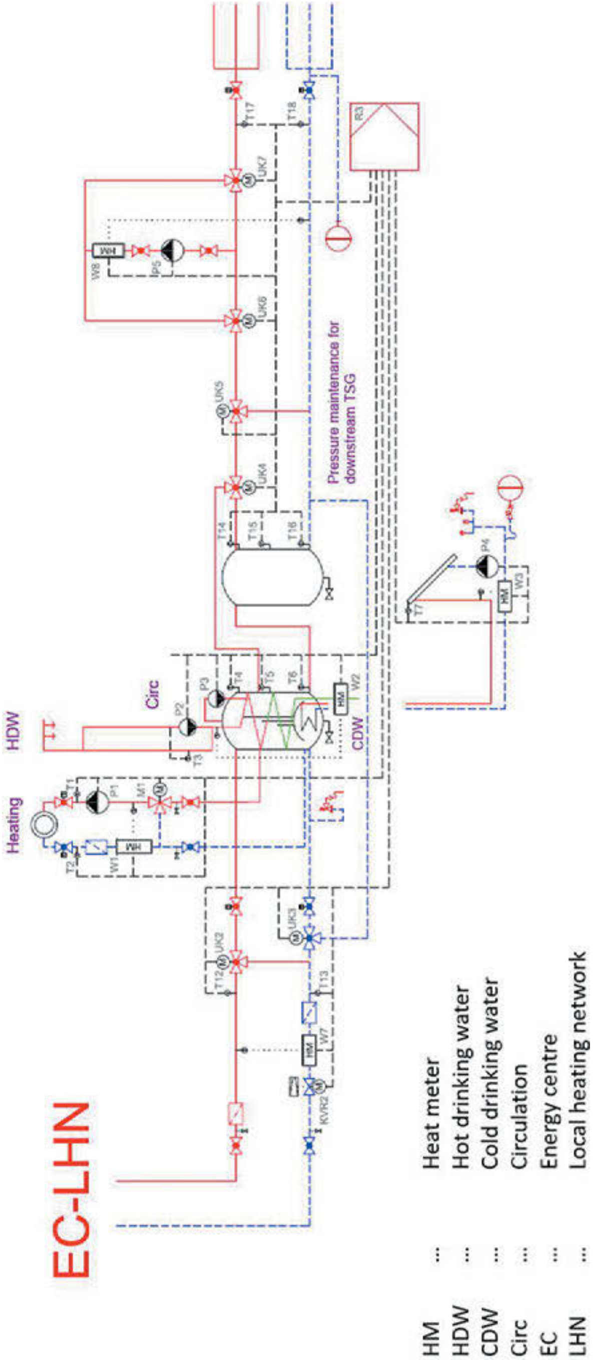

Figure 34.10: Hydraulic structure of an M-node with integrated solar thermal system.

of the heat transfer station in the technical building. Furthermore, an M-node has corresponding control and measurement components, safety devices and a pressure maintenance system for the respective network cluster. Additionally, the M-nodes form the distribution unit of the media flows (energy package dispatch) to and from the B-nodes and serve the building's own heat supply for heating and hot drinking water.

Cluster Z3 is designed with the operating mode as conventional local heating network and represents a comparison area with conventional use especially for further monitoring. For the storage, supply and billing of the heat quantities in the respective building, a network hydraulic unit (conventional local heating network- B-node), which is directly connected to the transfer station via the main line, was also developed on the basis of a B-node (cf. Figure 34.11). However, this node type has a reduced hydraulic structure compared to the Thermal Smart Grid B-nodes, as the nodes are subject to a conventional and thus continuous supply as conventional local heating network. Thus, the components for measuring delivered energy quantities and for starting and stopping the package delivery are omitted compared to the Thermal Smart Grid B-node.

In the area of residential buildings operated as conventional local heating network and between the heat transfer station and the M-nodes, the routes and pipes basically consist of flow and return pipes. This is different in the area of sequential supply by means of energy packages between M- and B-nodes, as the flow path can be reversed and thus the flow direction changes (see previous page). In this area, flow and return can only be spoken of in the respective operating case. In general, the pipelines are differentiated here into pipelines with a higher temperature and pipelines with a lower temperature, whereby both pipelines can function as a feed line or return line, depending on the operating case.

34.4.5 Control Concept and Operation Management of the Thermal Smart Grid

In the project ZED, a prototypical mathematical model of the Thermal Smart Grid process could be developed which applies to the heat supply in the supply network and to a network extension up to the radiators of the flats. In the following, special reference will be made to the descriptions of the supply network. Decentralised heat storage units play an important role in demand-controlled heat supply. These are the interface for the discontinuous, demand-driven supply of heat packages to the apartment blocks. They give flexibility to the supply and also guarantee security of supply.

The starting point is the loaded storage of the M-node and the unloaded storage of the B-node. Now the informational and hydraulic delivery process takes place. The B-node detects the unloading of the storage and sends a demand message to the M-node, which checks the readiness for delivery and releases the delivery cycle. When

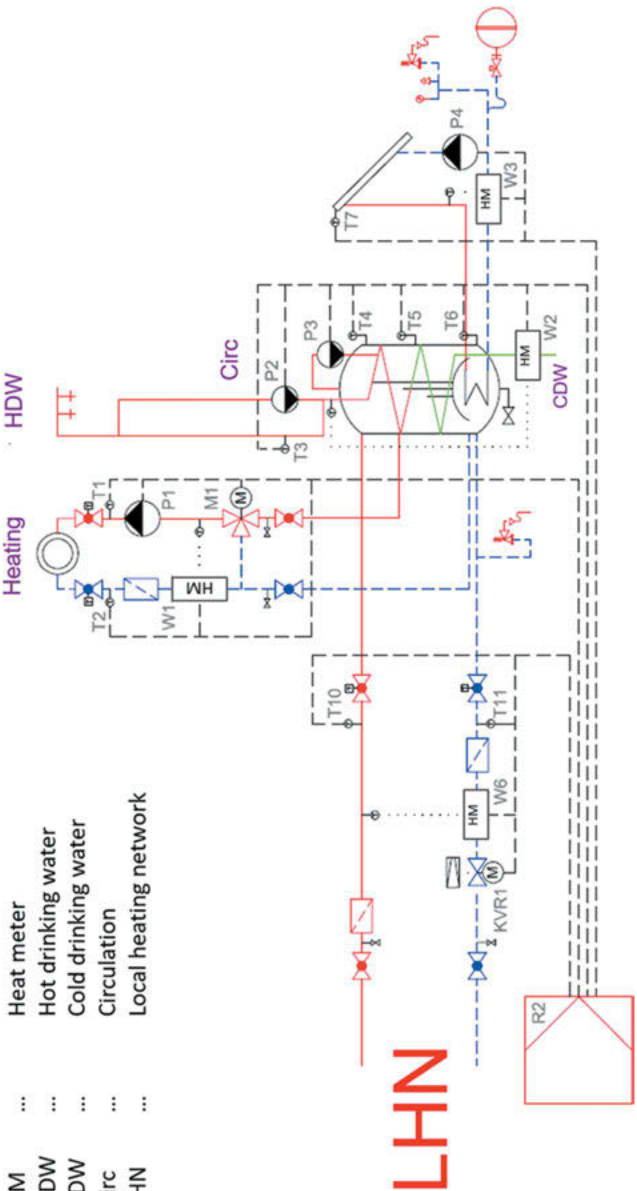

Figure 34.11: Hydraulic structure of a conventional local heating network B-node with integrated solar thermal system.

the delivery paths are released, the B- and M-nodes communicate to deliver a heat package, the flow path is switched and the pump group at the M-node is activated. Relevant variables of the heat package are the agreed upper network temperature (supply temperature of the heat generator) and the delivery volume. For an exact transfer of the necessary heat quantity of the package to the B-node, low-temperature water standing in the pipes is diverted into the lower network area via a bypass circuit. The B-node issues a message when the agreed quantity has been delivered. Thereafter, the delivery line is filled with low-temperature return water under the following circumstances. A regime for this was set up based on simulations as follows:

1. warm-up – delivery – cold run of the pipes
2. warm-up – delivery – leaving the warm water in the pipes
3. permanently warm pipes in continuous operation

The calculation parameter for selecting the operating mode was the minimisation of additional costs of the respective operating mode due to heat losses. At this point the delivery cycle is finished.

The described delivery cycle is applied with reversed temperature assessments and delivery directions as soon as a heat package is sent from the B-node to the M-node. This measure is required when installing a solar thermal system if excess heat is sent to the grid.

Extensive measurement and control technology is required to map and implement the control concept, which has been developed for each of the three node types (Thermal Smart Grid M- and B- nodes as well as conventional local heating network B-nodes) and is shown in the hydraulic diagrams (cf. Figures 34.9–34.11). The required field devices (sensors and actuators) for control, regulation, measured value and status recording and for energy quantity measurement have been defined for each node type. The equipment indicator (grey) establishes the reference between hydraulic diagrams and technical specifications of the equipment. The dimensioning and quantity determination is implemented according to the line and energy requirements of the network subscriber as well as according to the number of each node type in the network.

The control concept is described by means of function modules, which are implemented in the node controllers and can be activated or deactivated as required. For each function module, the requirements for the node controller, the control process for handling the control task and the required exchange of information between the nodes were developed. Separate considerations were made for the multivalent and the bivalent node controller in the Thermal Smart Grid and for the bivalent node controller in the conventional local heating network.

The M-node forms the hydraulically and informationally superordinate unit to the B-node in its network cluster. The B-node controller is a controller derived from the M-node with a smaller range of functions. The node controllers can be extended with additional function modules through updates / upgrades.

Defined Function Modules Independent of the Node Type

- measured value and status recording (heat meter, temperature sensor, valve position, etc.)
- data provision (Thermal Smart Grid process control, information and communication technology services)
- operational management in the Thermal Smart Grid
  - process management and organisation in the Thermal Smart Grid at M- and B-nodes
  - order processing and energy package management
  - storage management
  - oncident communication and emergency operation organisation
- operation management in the conventional local heating network
- heating control
- hot drinking water temperature and circulation control
- solar system control

From the product portfolio of Samson AG, which is the project partner and co-developer, the necessary control components for mapping and implementing the control concept as well as for controlling and reading out the field devices were selected. Furthermore, the control technology division of the concept was carried out according to the already defined network clusters and the allocation of the control devices to be used was modular for each of the three node types. The control applications for the residential area were divided into three sub-projects (network clusters Z1, Z2 and Z3, cf. Figure 34.6).

1. multivalent node K18 Windbergstraße (control central processing unit 1)
2. multivalent node K5 Ludwig-Erhard-Straße (control central processing unit 2)
3. conventional local heating network with compact controllers

The combination of a central processing unit and two input/output modules (I/O modules) is intended for the multivalent nodes K18 and K5. One I/O module is placed in each of the bivalent nodes K1, K2, K3, K4, K14, K15, K16, K17, K19, K20. The conventional local heating network -B nodes K6, K7, K8, K10, K11, K12, K13, K26, K27 in the network cluster Z3 are equipped with communication-capable compact controllers.

The central processing unit has several communication interfaces (Modbus RTU, Modbus TCP, TCP/IP), which serve as an interface to the higher-level information and communication technology. The algorithms for the individual function modules are implemented in the central processing unit software and thus form the node controllers. Furthermore, the historical data such as temperature curves of the storage temperature sensors are logged in the central processing unit and remote access to the freely programmable central processing unit is possible via the TeamViewer software. This allows the system to be monitored, modified and optimised at any time during operation. The I/O module is used to regulate, measure and control the field devices (sensors and actuators) on the multivalent and bivalent node via the I/O bus. The functional scope of this I/O module essentially concerns the execution of individual function modules, including temperature detection, the control of valves and ball valves and the detection of binary states, for example, of demand requirements.

In addition to the selection of suitable control devices, the development of the algorithms for the implementation of the function modules and especially the management, dispatch and planning of energy packages as well as the determination of the storage charging status and the determination of current offers and demands took place. For the demonstration and for test trials in preparation for practical implementation, a control simulation was developed based on the planned electronic control components from Samson AG for the Thermal Smart Grid. This control simulation was created for the network cluster Z1 in Windbergstraße in order to first map the functional principle of a network cluster, to test it and then to be able to scale it. It is used to simulate and test implemented controller applications and individual function modules. It is possible to test and further specify the charging behaviour of the storage tanks and the heat package control. The integrated Modbus TCP connection makes all relevant data available to the higher-level Kairos system and is also a control command receiver for the heat package management of the nodes. The demonstrator allows the charging speed of the storage tanks to be simulated as well as the energy flow direction and all temperatures, heat quantities and actuator controls to be observed and simulated. Accordingly, suitable calculation models were developed and implemented to simulate the behaviour of the components. The system demonstrator offers a web interface, as shown in Figure 34.12, which allows all settings for preliminary tests and visualises the results. It shows the hydraulic interconnection of the network nodes with the currently prevailing state values such as temperatures or operating states of pumps and valves.

The web view shows how the M-node 18 from buffer 1 (thermal multifunctional storage tank) feeds the bivalent node 17 with heat. The pumps are shown with a green colour change as active status and the pipes show the flow direction in bold. Parallel to this, the start of charging from the transfer station can be seen in the start-up mode of the thermal multifunctional storage tank in the multivalent node. The purple buttons on the right visualise the influence of the Kairos system on the charging commands in simulation mode, which can be readjusted manually by mouse click. After the switchover in the real lab, these buttons are no longer made available; the commands then come into the system exclusively from the Modbus interface. With the web view, every operating situation in the network can be displayed, such as the heat package transfer from the B-node ready for delivery to the M-node, the loading of the M-node from the transfer station, all start-up or shut-down states as well as active thermal solar surfaces.

The web application also has the option of calling up several submenus to visualise further views of subassemblies, such as the control behaviour of a heating circuit.

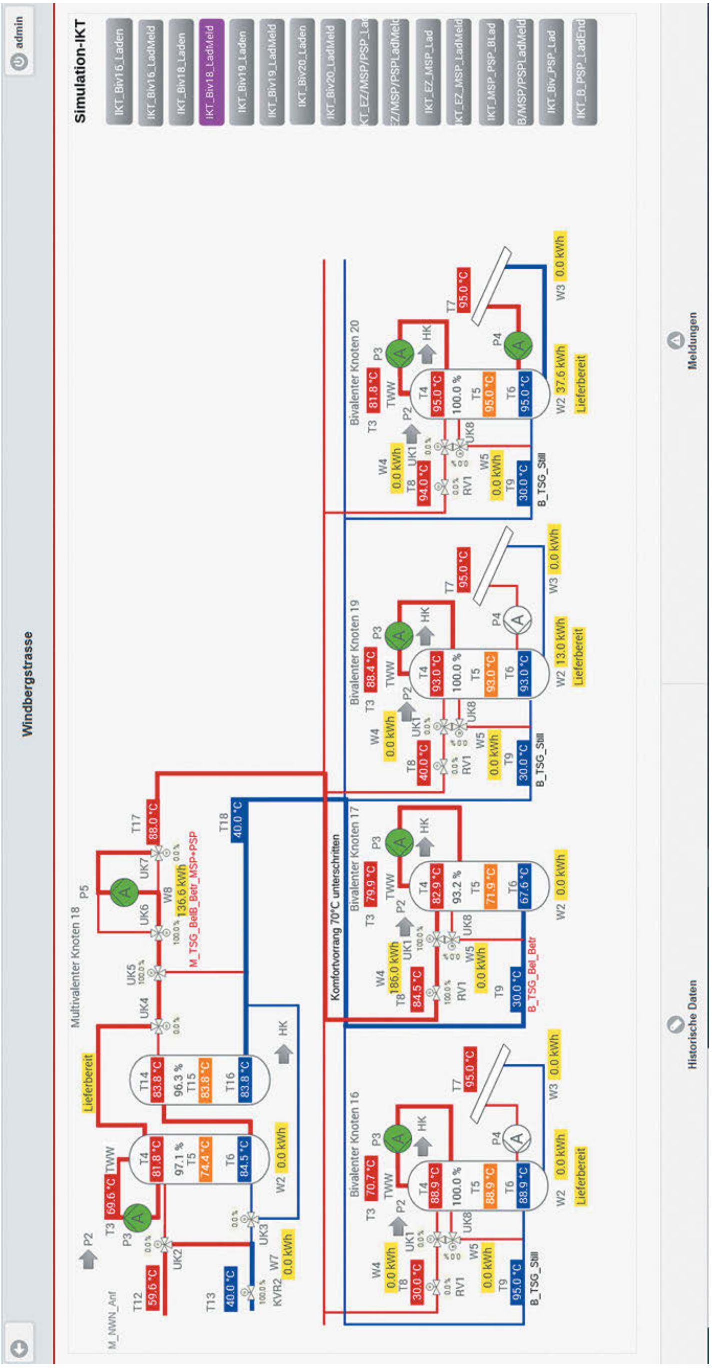

Figure 34.12: System demonstrator for control simulation in grid cluster Z1.

In addition to visualisation, it is also possible to define various setting parameters in a user interface, including temperature thresholds or switching temperatures. At this point, adjustments can be made as desired, depending on how the system reacts, or optimisations can be achieved for the comfort of the occupants. Furthermore, the operating modes of the nodes can be parameterised. These settings allow, for example, individual nodes to be deactivated or activated if only some of the nodes are installed in the planning area. Additionally, partial start-ups can be started. Switching from the simulation mode of the system to the active real laboratory is also accommodated. In future practical system operation, it will be possible to observe and monitor the system remotely via TeamViewer and to carry out optimisations in practical operation.

Implemented control algorithms are tested, evaluated and adapted. The control simulation is constantly modified in order to simulate the real state as best as possible. An example of this is the adaptation of the building model through heating circuit control based on the outdoor temperature. For this purpose, a model of the weather-compensated power demand is determined and implemented. Furthermore, the modelling and simulation of the dynamic behaviour of the return temperatures, the start-up and shut-down times of the pipe connections between the nodes and the modelling of the storage capacities as well as the loading and unloading behaviour of the heat storage tanks are carried out.

34.4.6 Operating Cases and Energy Package Dispatch in the Thermal Smart Grid

In the controller application, the function module for process control and organisation in the Thermal Smart Grid is of essential importance for the energy package and storage management between the individual network participants. To achieve a systematic approach to the possible switching states in the complex hydraulics of M- and B-nodes, taking into account the correct flow paths, operating cases were defined for each of the nodes. Two groups of operating cases must always be distinguished at the M-node, as these nodes are always connected to an upstream and a downstream network.

The operating cases at the M-node are divided separately into conventional local heating network and Thermal Smart Grid since the M-node has an upstream conventional local heating network and a downstream Thermal Smart Grid. At the M-node there are a total of four conventional local heating networks and seven Thermal Smart Grids operating cases and at the B-node five Thermal Smart Grid operating cases have been defined. The necessary operating case combinations have been derived from the definition of the operating cases. A total of 35 necessary operating case combinations have been identified and a separate hydraulic diagram has been created for each operating case combination, showing the flow path.

In the following explanations, the system for determining the storage charging state and for sending a hot energy package from an M-node to a B-node is described as an example using operating cases and their combinations. The conventional local heating network operating cases at the M-node are not considered. Other operating systems are necessary, such as those listed below. However, these operating systems will not be discussed in detail in this article:

- dispatch of an energy package from a B-node to an M-node
- energy purchase from the heat transfer station
- order processing and energy package management
- incident communication
- emergency operation organisation

The state of charge of the storage tanks is recorded by the temperature sensors distributed over the height of the tank. If all temperatures have reached the required setpoint temperature, the storage tank has a state of charge of 100%. If hot water and energy is taken from the upper part of the storage tank, its energy content decreases and the state of charge decreases. Cold return water flows into the lower part of the storage tank and continuously lowers the temperature from the bottom to the top. As a result, a transition layer forms between cold water (below) and hot water (above), which moves in the storage tank above its height. This temperature change in the storage tank is recorded and evaluated in the controller application in the function module for storage tank management. If the transition layer has been registered at the middle or upper temperature sensor, the storage tank has a state of charge of 50% or 30%. Likewise, a forecast of the remaining discharge time is possible through the current demand recording and the current state of charge of the storage tank. The existing energy content / state of charge is considered. This also has an impact on subsequent demand, order processing and energy package management.

The starting point for the description of the dispatch system of an energy package from an M-node to a B-node is the operating case combination 01 (see Figure 34.13). The Thermal Smart Grid and the upstream conventional local heating network to the heat transfer station are at a standstill and all storage tanks have a state of charge of 100%.

In the B-node, the discharge of the thermal multifunctional storage tank takes place through the withdrawal of hot water to cover the heating demand and to heat the domestic hot water. As described above, this discharge is recorded via the temperature sensors on the storage tank and evaluated in the controller application. The current state of charge and the remaining discharge time until the required arrival of the energy package is communicated to the M-node so that the processing and energy package management can be bearded in mind. If an energy package is sent from an M-node to a B-node, the cold water must be displaced from the line from the M- to the B-node at the beginning. For this purpose, the necessary operating cases are switched at the M-node and B-node and the flow path is switched as shown in Figure 34.14 and the pump is started up. The energy package displaces the cold water in the direction of flow, which is fed to the return flow via the bypass at the B-node.

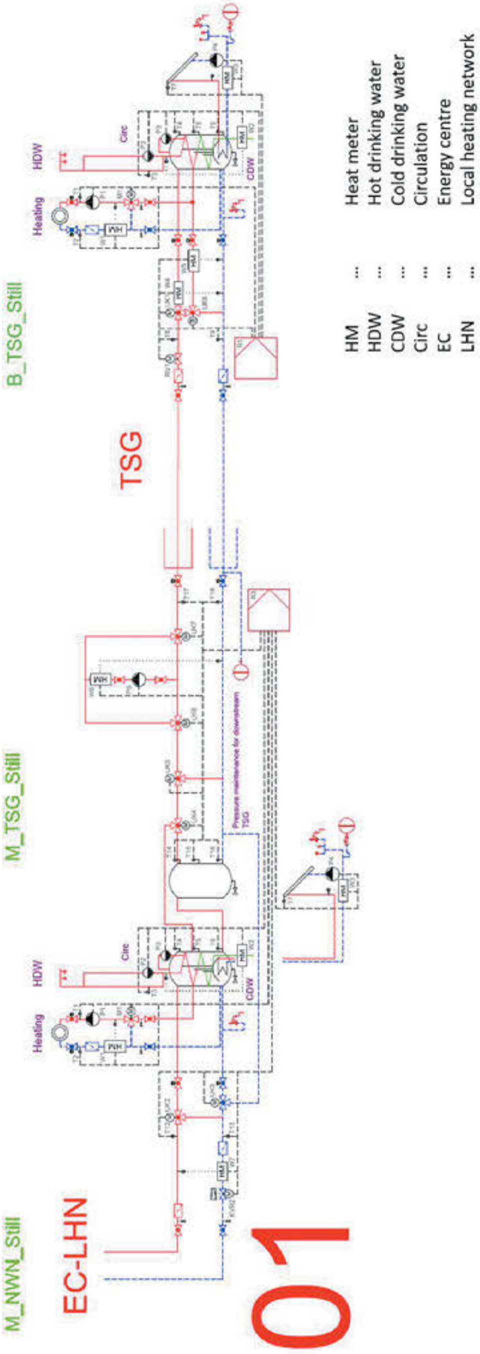

Figure 34.13: Hydraulic illustration of the operating case combination 01.

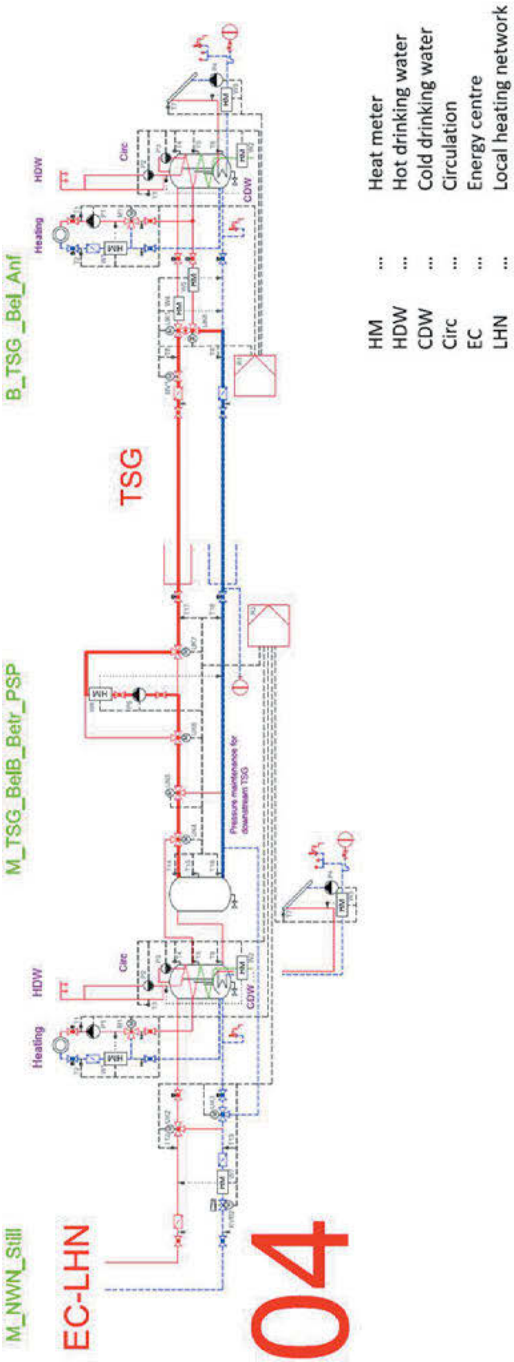

Figure 34.14: Hydraulic illustration of the operating case combination 04.

Once the start of the energy package has arrived at the B-node, the operating state “start-up” is changed to “loading” at the B-node and the energy package is fed to the thermal multifunctional storage tank, see Figure 34.15. The operating state at the M-node remains unchanged at this point. To prevent part of the energy package from being fed to the return or cold water from flowing through the thermal multifunctional storage tank, the exact switchover time between the two operating cases is determined.

As soon as the thermal multifunctional storage tank can only hold the line content between the two network participants, the operating state at the M-node changes from loading the B-node to “shutting down”. This ends the withdrawal from the buffer storage at the M-node and cold water flows from the return into the supply, see Figure 34.16. The operating state at the B-node remains unchanged at this point. The cold water displaces the energy package in the direction of flow, which continues to be supplied to the thermal multifunctional storage tank at the B-node. The remaining part of the energy package (line content) is completely stored in the thermal multifunctional storage tank. The exact determination of the switchover time between the two operating cases takes place.

When the end of the energy package has arrived at the B-node, the delivery of the energy package is also completed. For this purpose, the M-node and the B-node switch to the idle mode and the pump is taken out of operation, see Figure 34.13. At this point, the thermal multifunctional storage tank at the B-node has a loading state of 100% and the buffer storage at the M-node must be recharged via the upstream conventional local heating network or via a B-node with energy surplus.

34.4.7 Energy Balance of the Conception

The energetic considerations of the concepts created in the project result in significant savings of primary energy and CO_2 emissions in each case. Through extensive simulations and the balancing of the overall concept, it was possible to determine a considerable saving of CO_2 through the use of the Thermal Smart Grid, regenerative energy sources and through conversion to another form of primary energy use. As described in Chapter 34.3.2, roof area occupancy with solar thermal systems of 0%, 5% and 10% were simulated in the variants V1 to V3 and taken into account in the energetic and CO_2-specific balancing. Figure 34.17 shows the qualitative and quantitative representation of the energy flows of the concept in a Sankey diagram for the supply option G2-V2-5%, which was further developed until it was ready for implementation.

The concept for the heating and cooling supply of the school enables the combination of a brine/water heat pump in heating and cooling mode, a photovoltaic system and an electricity storage system in a thermal-electrical compound system. For the simulation, the brine/water heat pump in heating and cooling mode was assumed to have an electrical reference line of 20 kW and a coefficient of performance of 4 and an energy efficiency ratio of 3 were specified. The electricity storage has a capacity of

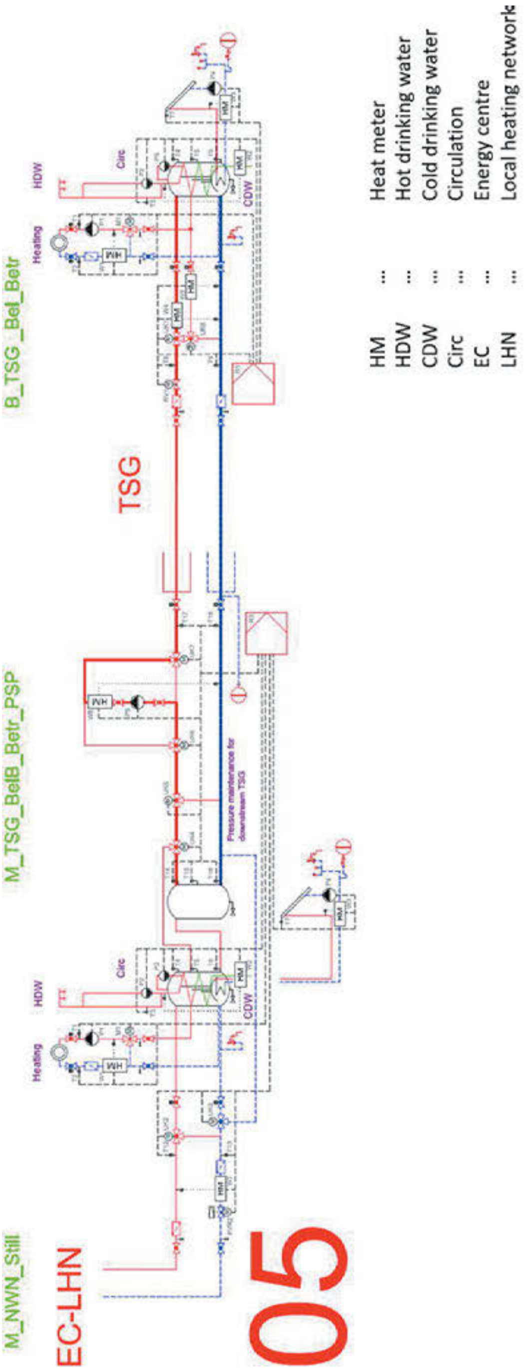

Figure 34.15: Hydraulic illustration of the operating case combination 05.

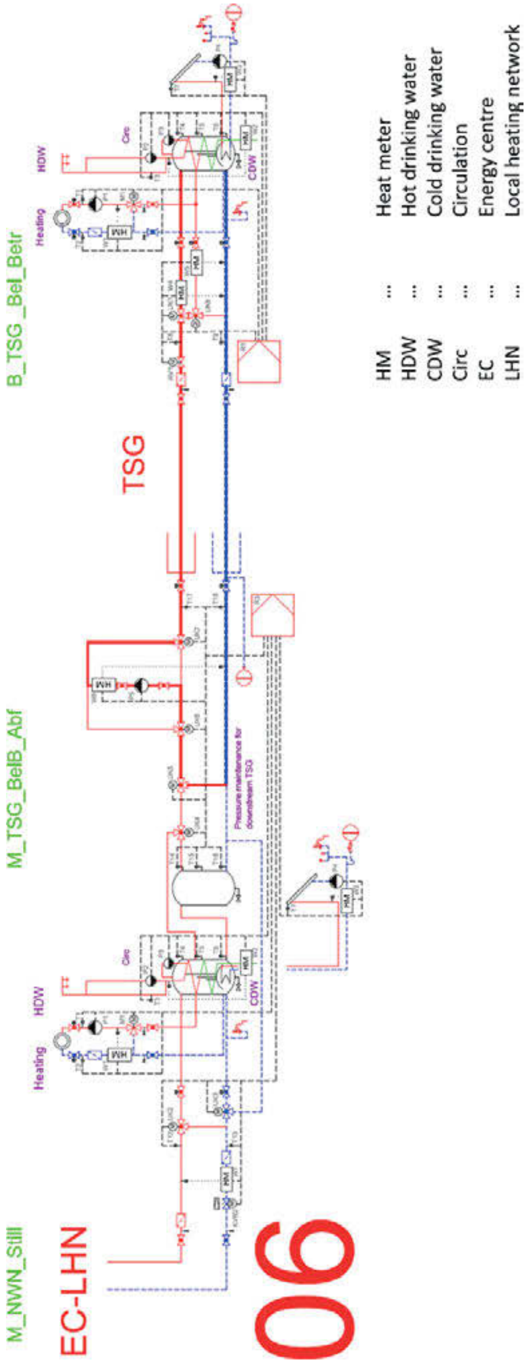

Figure 34.16: Hydraulic illustration of the operating case combination 06.

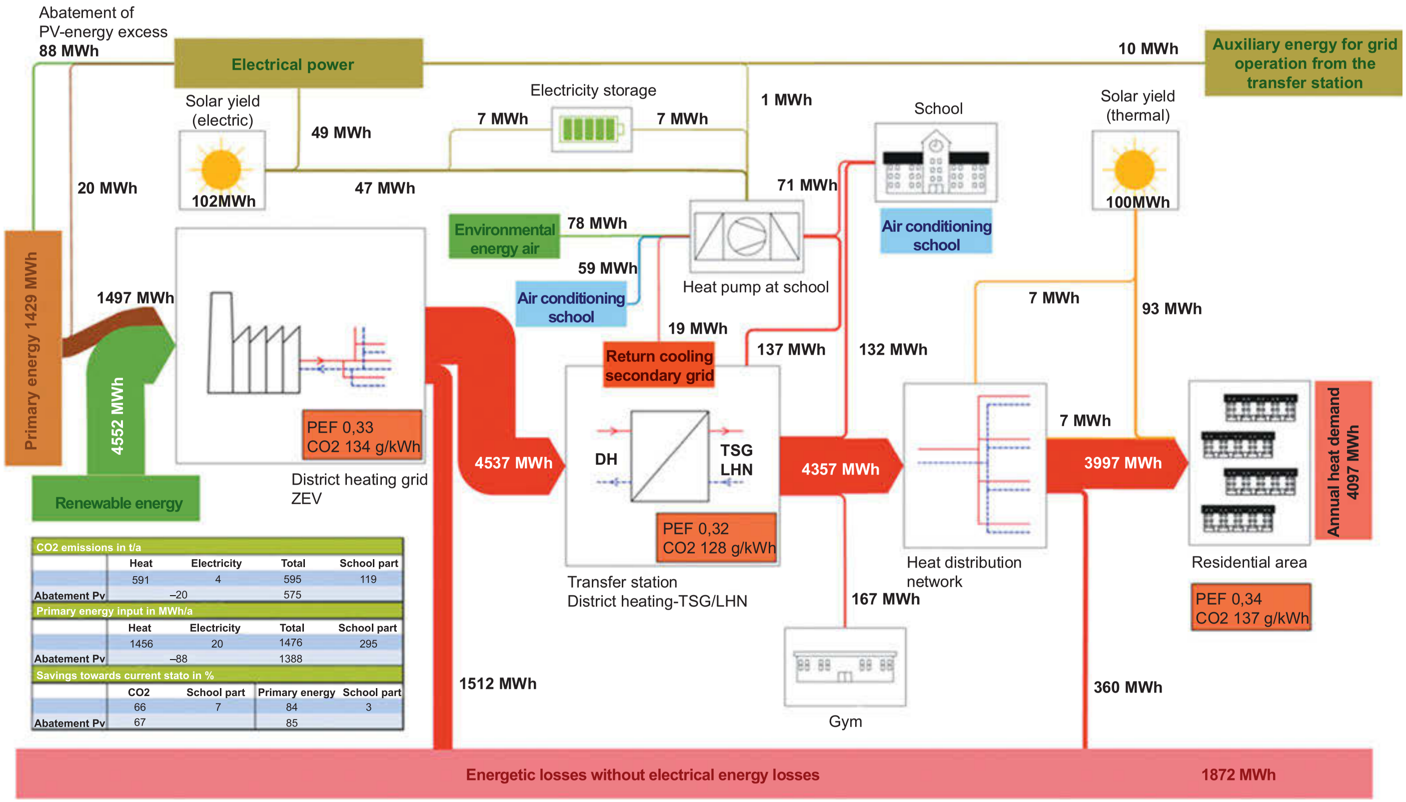

Figure 34.17: Energy balance for option V2 5% S (equipment Thermal Smart Grid with 5% roof surface occupancy with solar thermal surfaces) for the overall concept.

50 kWh. The cooling energy for air-conditioning the school of 59 MWh is generated exclusively by the brine/water heat pump in heating and cooling mode. The brine/water heat pump in heating and cooling mode also

contributes a significant 71 MWh of the total thermal energy demand for heating the school, and only a small portion of 132 MWh is taken from the secondary grid. The surplus of 137 MWh, which cannot be used in the school building, is fed into the secondary grid. As source energy, in addition to air conditioning, 78 MWh are taken from the ambient air and 19 MWh from the return flow of the secondary grid. The photovoltaic system has a total energy yield of 102 MWh, of which 47 MWh is used directly by brine/water heat pump in heating and cooling mode, 7 MWh is temporarily stored in the electricity storage system and 49 MWh is fed into the electricity grid.

Furthermore, the balance of the entire energy flow chain from the required primary energy to the useful energy demand of the buildings in the supply area is shown, including all solar gains and all thermal losses. The annual heat demand of the residential buildings is 4097 MWh. 93 MWh of this thermal solar energy can be used directly in the buildings and 7 MWh are redistributed through the Thermal Smart Grid in the heating network. Through the transfer station, 4537 MWh of thermal energy will be taken from the district heating network to cover the heat demand for residential buildings as well as the school and gymnasium.

In total, the CO_2 emissions can be reduced to 595 t/a in the overall concept. This corresponds to a 66% reduction in CO_2 emissions compared to the current situation. Primary energy use can be further reduced to a total of 1456 MWh/a, which corresponds to a reduction of 84% compared to the actual situation. The photovoltaic electricity fed into the power grid is credited to the overall system in the balance sheet by reducing the sum of CO_2 emissions and primary energy demand. The renovation of the school reduces the energy demand in the overall system. This reduction is additionally shown as a school share so that this can be considered when assessing the results and this is not added to the effects of the overall concept. The considerable reduction in each case is achieved primarily through a high proportion of renewable energies (ecological district heating, environmental energy, solar thermal energy, photovoltaics) and through a reduced electricity demand as well as heat loss in heat distribution through the Thermal Smart Grid. To a large extent, additional potentials made possible by the Thermal Smart Grid, such as the redistribution of thermal solar energy, have a positive effect on CO_2 emissions and primary energy demand.

34.5 Final Consideration

Within the framework of the research project ZED it was possible, among other things, to demonstrate a concrete way to modernise an existing local heating network, consisting of 21 residential buildings and a school / gym, in a flexible and modular way. In cooperation with the regional project partners, the city of Zwickau, the building and property company and the Zwickau energy supply company, a contribution was made to the concrete implementation of the energy transition by designing new networking strategies and decentralised storage. An innovative heat supply concept was developed for the quarter as a thermal-electrical compound system. The heat distribution follows the approach of a Thermal Smart Grid, whereby bidirectional energy packages are sent between the network participants. In the overall structure of the real laboratory, a CO_2 saving of 66% and a primary energy saving of 84% can be realised after application of the concept, considering real implementation conditions.

The investigation of the economic implementation of the heat supply concept as a thermal-electrical compound system is a complex task and depends on many factors, such as connected load, annual energy demand, supply network structure and number of network participants. Because of this, only a heat supply concept specifically designed for the quarter can provide an examination of the economic viability. The municipal energy supplier, which acts as investor and operator, developed an economic analysis taking into account investment, consumption and operating costs as well as public subsidies. As a result, a competitive mixed heat price was determined for this heat supply concept, considering all energetic and ecological advantages and a high level of supply security in the current global political situation. This statement is also made clear by the willingness of the municipal energy supplier to invest and by the willingness of various housing companies to connect.

Based on the results of previous research projects, various concepts and variants for energy supply were developed based on an analysis of the current state of the existing network and the buildings. For this purpose, the procedures of the M- and B-nodes could be further developed and adapted to the local conditions. The integration of regenerative energies was basically designed flexibly; solar thermal systems were used in the quarter. By planning a photovoltaic system on the roof of the adjacent school “Schule am Windberg”, developing a concept for cooling and heating the school and integrating it into the Thermal Smart Grid, it was possible to realise a sector coupling. In addition, the concept was examined in detail at the energy, network hydraulic and regulation technology (German: MSR technology) levels. Through the integration of a holistic control system by Samson AG, the system also offers a flexible connection to data processing and makes a sustainable contribution to digitalisation.

The present concept exemplifies a possibility of restructuring existing energy supply systems into modern intelligent systems, while maintaining security of supply. Due to its modular structure, the system is scalable with minimally invasive effort in new building construction as well as to existing buildings.

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Shengqing Xiao, Dimitri Nefodov, Markus Richter, Thorsten Urbaneck

35 Heat-Pump-Based Local District Heating System with Hot Water Store

Summary: A new concept for the energetic development of a zero-emission quarter (living lab) was investigated within the framework of the joint project "Demonstration of German Energy Transition in Zwickau". The system design provides the use of heat pumps and thermal energy storage for the residential district heat supply. The current work deals with the use of return flow of an existing district heating network as the heat source of the heat pumps. The energy efficiency of heat pumps (coefficient of performance) strongly depends on the refrigerant used. Here, we present the theoretical investigation of two heat pump configurations as well as operating strategies: a) Installation of a mixing system in the heat pumps with standard temperature spread in the evaporator (5 K) and b) constant water flow through the evaporator with varying temperature spread up to 15 K. The heat pumps were simulated using the program EBSILON®Professional. Furthermore, an optimal design is necessary to fulfill the goals while adhering to the constraints. TRNSYS 18 is used for modeling and simulation of the heat supply system.

35.1 Introduction

Urban district heating using renewable energy sources has a great potential to achieve Germany's climate protection targets. One major reason for this is that a large part of the population in Germany lives in cities (77.5%, as of 2020 (Statista 2021)) and the heat supply (space heating and hot water) accounts for about 31.9% (as of 2021 (BMWi 2021)) of the final energy consumption in Germany.

As part of the project "Demonstration of German Energy Transition in Zwickau" (Zwickauer Energiewende Demonstrieren – ZED), the authors planned a (nearly)

Acknowledgements: This work was funded by the German Federal Ministry for Economic Affairs and Energy under grant number 03SBE114C on the basis of a resolution of the German Bundestag. The authors also thank the project management organisation Jülich for supporting the project. The responsibility for the content of this publication lies with the authors.

Shengqing Xiao, Dipl.-Ing., is research associate at the Chemnitz University of Technology
Dimitri Nefodov, M. Sc., is research associate at the Chemnitz University of Technology
Markus Richter, Univ.-Prof. Dr.-Ing., is head of the Professorship for Applied Thermodynamics at the Chemnitz University of Technology
Thorsten Urbaneck, Prof. Dr.-Ing. habil., is leader of Division Thermal Energy Technology, Professorship Technical Thermodynamics at the Chemnitz University of Technology

https://doi.org/10.1515/9783110777567-035

emission-free, reliable and economical heat supply for the Marienthal district in Zwickau (Germany). For this purpose, a heat-pump-based district heating system with a hot water store was favored. The heat pumps enable an environmentally friendly and energy-efficient heat supply if renewable energy sources are applied. It is also possible to use waste heat (e.g., from industrial processes) or heat that cannot be used elsewhere as the heat source. The hot water store can balance the load and thus helps to optimize the heat pumps' operation.

In the first part of this work, the boundary conditions and the system design are presented. An important focus is the discussion of possible usable heat sources in urban districts. This is followed by a description of the models, created using EBSILON (STEAG 2019) to simulate the heat pumps and the results obtained. In the third part of this work, parameter studies carried out with TRNSYS 18 (TRNSYS 2019) show the influence of different parameters, which are important to fulfill the goals mentioned above.

35.2 Boundary Conditions and Technical Approach

According to the assumptions, the district concerned comprises about 800 residential units with a living area of about 38,950 m^2 and an elementary school with a gymnasium.[1] The information about the buildings in this district was presented in (Nefodov/Xiao/Urbaneck 2019) and (Xiao/Nefodov/Urbaneck 2020). The sorted and normalized values for the network heating load (TRY2011) including the network losses for the entire district in comparison to the values of the Brühl district in Chemnitz (Germany) (Shrestha/Urbaneck/Oppelt et al. 2018)[2] (measured values 2018) are shown in Figure 35.1. According to the assumptions made, the peak load is about 1,644 kW and the annual heat consumption $Q_{\mathbf{Net}}$ is 5,167 MWh/a. The calculation of the annual heat load for the residential buildings in the Marienthal district was carried out by the project partner Westsächsische Hochschule Zwickau, Institute of Energy and Transport in the Chair of Thermal Engineering/Computer-aided Planning Methods. (Hoffmann 2021) The calculation was based on the recorded consumption data. Subsequently, the values were adjusted for the test reference year 2011. A heating curve was used to determine the load values for the school. Both curves in Figure 35.1 have a comparable development, which confirms the distribution of the heating loads. Figure 35.2 shows the distribution of the monthly heating loads. Due to the very good thermal insulation of the building envelope and the compactness of the district size, the loads in winter are comparatively low (specially in Marienthal district).

1 Total area of residential district $A_{G,Q}$ is 42,335 m^2 according to internal assumptions.

2 But the Brühl district in Chemnitz is significantly larger than the Marienthal district in Zwickau. However, there is a strong correspondence between their network temperatures, buildings (renovated apartment buildings with commercial units) and their use. Climatic conditions in both regions are also similar.

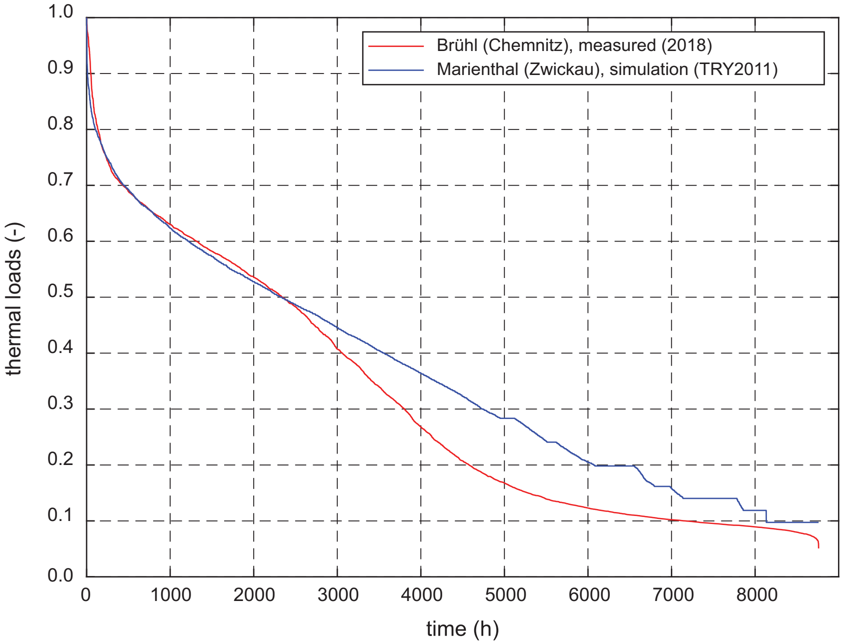

Figure 35.1: Comparison of normalized heating loads of the local heating networks (inclusive of network losses) Brühl (Chemnitz, Germany) and Marienthal (Zwickau, Germany), dimensionless and sorted loads.

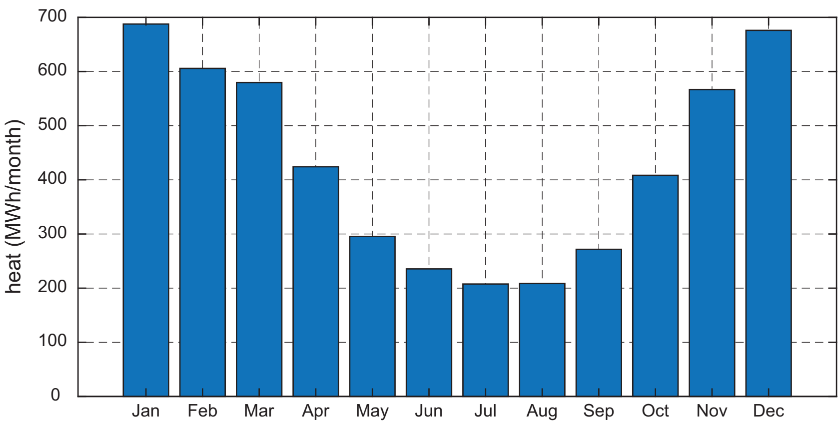

Figure 35.2: Monthly heating loads of the local heating network in Marienthal (Zwickau, Germany), simulation results (TRY2011).

Although the buildings were renovated after 1990, the supply temperatures for space heating (70/55 °C) remained at the same level. In the subsequent modeling and simulations, it was assumed that the heat generators supply with a temperature of 75 °C

(Figure 35.3). Based on the measured return temperatures from the Brühl local heating network in Chemnitz (cf. Shrestha/Urbaneck/Oppelt et al. 2018), an annual course of the return temperatures T_R in the Marienthal local heating network was assumed.

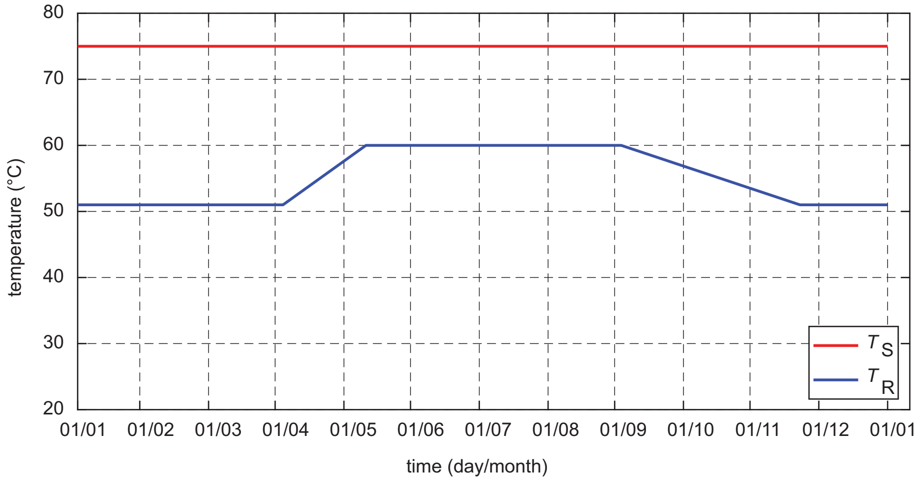

Figure 35.3: Simplified supply and return temperatures in the Marienthal local heating network, assumption based on (Shrestha/Urbaneck/Oppelt et al. 2018).

In most residential districts, there is usually no industrial waste heat available. Depending on local conditions, environmental energy (e.g., solar, air, geothermal) and wastewater systems are available as optimal heat sources. Solar thermal energy is a proven and geographically unlimited solution to avoid emissions. A relatively inexpensive variant for the implementation of solar thermal energy in districts enables the ground-mounted system. In this case, the prerequisite is that open land is available in the district for the collector field. Roofmounted system in existing buildings (multi-family houses) requires a higher investment, especially if the roof has to be renewed. In the Marienthal district in Zwickau, the available open land is strongly limited.

Through the proposal of the local municipal utility company Zwickauer Energieversorgung ZEV from 06 March 2019 for the use of the heat from the city's district heating return pipe, a promising system variant is developed and presented here. The district heating return pipe enables a withdrawal of 78.5 m^3/h in winter and 52.33 m^3/h in summer. A biomass cogeneration plant takes over the main supply of the district heating network.[3] The additional cooling of the return flow increases the energetic utilization of the fuels (e.g. wood chips) (Nefodov/Xiao/Urbaneck et al. 2021).

3 This can be considered as a use of "green" heat (Nefodov/Xiao/Urbaneck et al. 2021).

Figure 35.4 shows the system design for this variant. The system has two identical heat pumps of one type to ensure redundancy. The discussion on the selection of the optimal refrigerant is presented in Chapter 35.3. The power supply of the system should be provided from renewable energies (e.g., wind, PV).[4]

The heat pumps hydraulically separate the heat source (city's district heating return flow) and the heat sink (local heating network). The heat pumps can achieve relatively high coefficients of performance, since the temperature difference between the heat source (approx. 50 . . . 54 °C) and the heat sink (approx. 70 . . . 75 °C) is comparatively small. A lower electricity demand of the heat pumps leads to a reduction of the consumption costs.

The hot water store can be implemented as a compact storage tank (e.g., flat-bottom tank). Due to the construction and thermal insulation, the hot water store in this case has relatively low heat losses. The regular storage operation realizes a balancing of loads (e.g., peak load coverage) and enables various optimizations. These include, for example, the operation of heat pumps with high coefficients of performance as well as the avoidance of heat pump operation at minimum network loads, in which the heat supply of the local heating network is carried out exclusively by the hot water store. In addition, there is the possibility of pre-production of heat under favorable conditions, such as low electricity prices or high availability of electricity from renewable sources. If required, the system design allows the direct coupling of additional heat generators (e.g., solar thermal collectors) to the storage tank.

35.3 Modeling of the Heat Pumps

The energy efficiency of heat pumps (coefficient of performance) strongly depends on the refrigerant used. According to the EU F-Gas Regulation No. 517/2014 (EU 2014), a gradual phase-out of high-GWP refrigerants is planned. The use of many previous commercial refrigerants in heat pump systems are limited in the foreseeable future due to their high global warming potential. In addition, most low-GWP refrigerants for heat pumps place high demands on safety engineering due to their flammability or toxicity.

Theoretical investigations of low-GWP refrigerants were carried out in project. The refrigerants considered for the heat pump system for local heat supply must be commercially available, compatible with the compressors and other system components and applicable under the safety regulations. According to the EU F-Gas Regulation No. 517/2014 (EU 2014), only refrigerants with GWP below 1500 are to be considered in the project and the sustainable refrigerants with GWP below 150 are preferred. The investigations on refrigerants conducted in the project have shown that most optimal sus-

4 Internal project assumption.

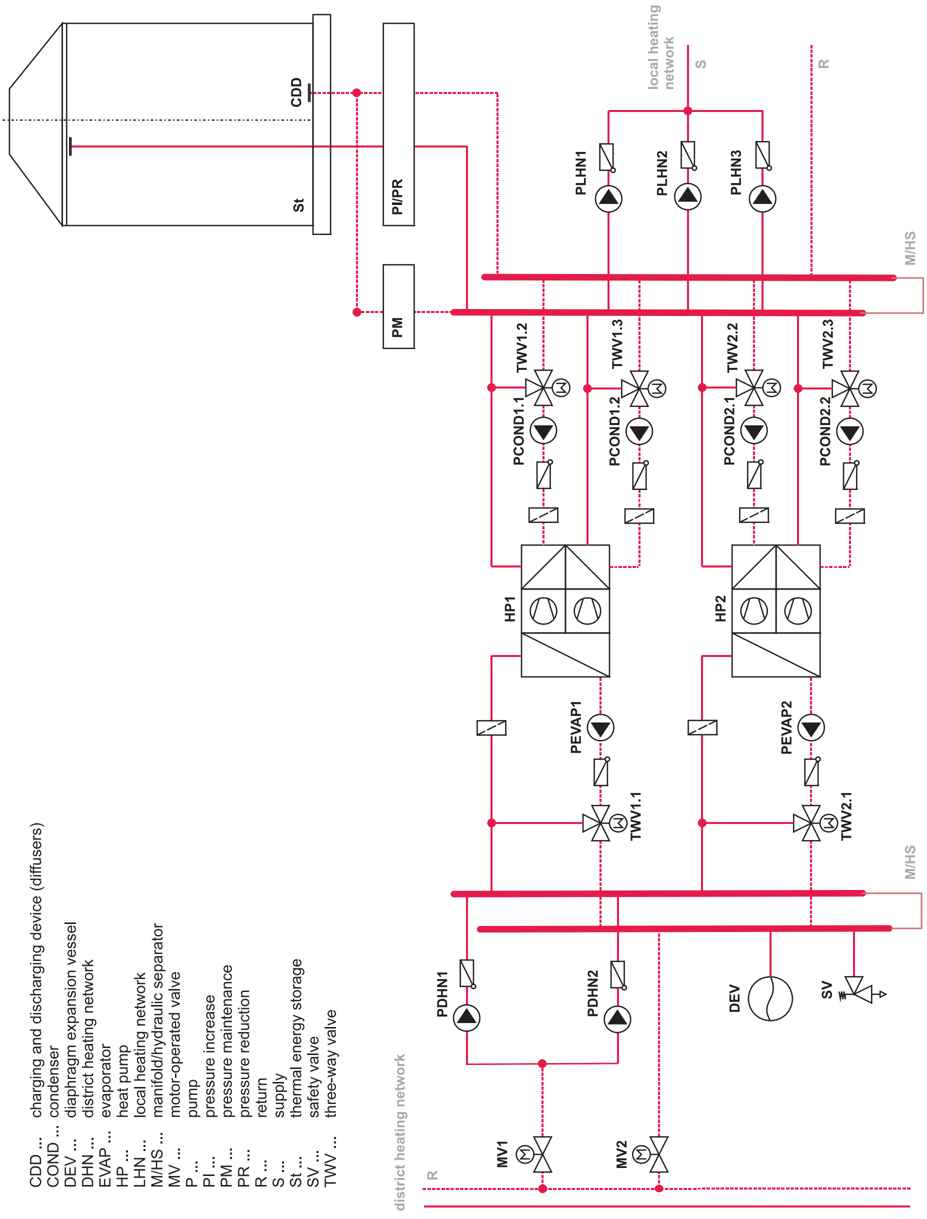

Figure 35.4: Simplified diagram for the (district) central heating plant with the cooling of the city's district heating return flow.

tainable working fluids for the large-scale heat pumps for local heat supply are at least low-flammable or toxic. Among all refrigerant candidates, R1234ze(E)[5] has the best thermodynamic properties as well as the fewest safety issues. This refrigerant is used in the following modeling and simulations of the heat pump system.

R1234ze(E)[5] is classified in the safety class A2L (non-toxic, low–flammable). The use of this refrigerant in future local district heating systems in compliance with German and European safety regulations can be considered acceptable.[6] The maximum permissible refrigerant charge or the minimum installation area for most indoor machines is specified in the German standard DIN EN 378–1 (DIN 2018) depends on the toxicity and flammability of the refrigerants. The heat pumps should be installed in a machine room accessible only to authorized persons. The machine room is equipped with the necessary safety equipment, a fire alarm system, a gas warning system, an emergency ventilation, etc. These technical requirements are also specified in DIN EN 378–3 (DIN 2017). There is no limitation of the refrigerant charge.

In addition to meeting all safety requirements, operators of equipment containing fluorinated greenhouse gases in quantities of five tons of CO_2-equivalent or more are required by the EU F-Gas Regulation No. 517/2014 (EU 2014) to have the equipment regularly inspected for leaks by an expert and to keep an operating manual documenting this. The inspection interval for leakage checks depends on the refrigerant charge. To prevent the escape of fluorinated greenhouse gases into the atmosphere, the maximum permissible specific refrigerant loss from the stationary system during normal operation is specified in the ChemKlimaschutz dated 14 February 2017 (BMJV 2008). This regulation also requires that all companies handling refrigerants containing fluorine must be certified.

The limited heat source volume flow leads to the fact that the heating capacity of standard heat pumps with relatively small temperature spreads (3 … 5 K) in the evaporator is not sufficient to cover the required heating capacity in winter. In this context, two heat pump cycles or operating strategies are theoretically evaluated using the software EBSILON®Professional. (STEAG 2019) After agreement with the manufacturer, the water flow rate through the heat exchangers can vary between 75% and 100%. In variant a), the heat pump system consists of two single-stage standard heat pumps (5 K temperature spread in the evaporator) with mixing circuits on the heat source side (Figure 35.5). This mixes the evaporator outlet water with the inlet water and thus reduces the temperature of the evaporator. This increases the temperature spread on the heat source side ($T_{so.in} - T_{so.out}$) and consequently the heating capacity. In variant b), two parallel connected identical refrigeration cycles (cycle a and cycle b) are coupled together by a common evaporator (Figure 35.6). The evapo-

5 R1234ze(E) is trans-1,3,3,3-tetrafluoroprop-1-ene with ODP of 0 and GWP<1. The suffix (E) indicates that it is an isomer (Honeywell 2017).

6 The choice of refrigerant is an extensive subject. For the selection of the suitable refrigerant (cf. Xiao/Nefodov/Richter et al. 2022).

rator has four connections. This allows the refrigerant of the two refrigeration circuits to flow separately through the apparatuses. Each circuit has a single-stage compressor and a condenser. The water (heat source) can be cooled up to 15 K.

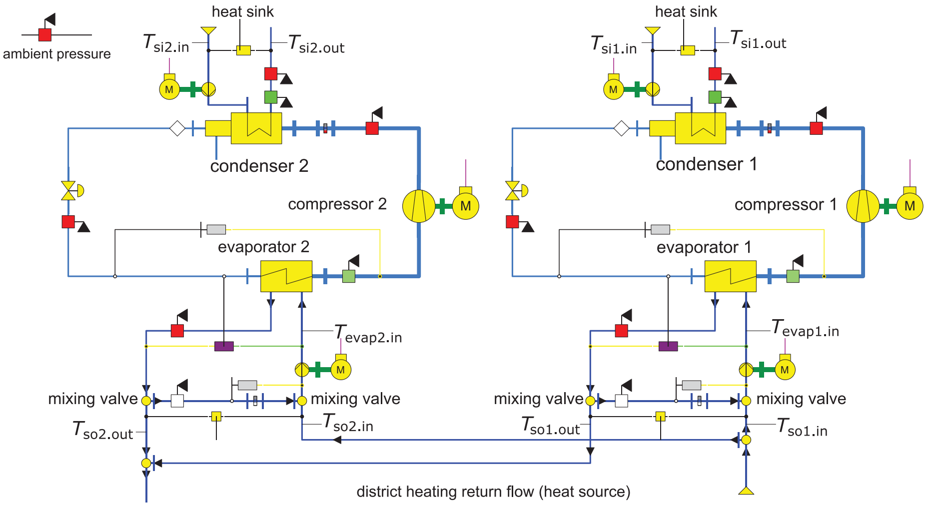

Figure 35.5: Heat pump variant a), EBSILON model.[7]

The simulated operating points of the heat pump variants a) and b) are summarized in Figure 35.7. The diagram compares the heat pump coefficients of performance in relation to the heating capacities. The COPs of variant a) are above five in the low capacity range (approx. 300 … 700 kW). For heating capacities between 700 kW and 900 kW, the coefficient of performance drops drastically. A further increase in heating capacity leads to poor coefficients of performance below three. Compared to variant a), variant b) has a significantly larger capacity range up to approx. 1,750 kW. The higher heat pump capacity allows a smaller hot water store construction. Thus, the total system costs can be reduced. The coefficient of performance decreases only slightly with increasing heating capacity, so that variant b) works more efficiently than variant a) from approx. 750 kW. The operating behavior can be explained from the operation of both circuit variants. Limited volume flow and low temperature spread mean that variant a) cannot provide the necessary thermal output. Higher temperature spread in variant b) solves the problem.

Based on the simulated operating points, the heating capacity levels are selected and the heat pump operation is designed accordingly. Figures 35.8 and 35.9 show in principle the developed operating strategies for the heat pump variants a) and b). In

7 The small squares in the EBSILON model are control units with each color representing a specific control parameter such as pressure, temperature, mass flow rate etc.

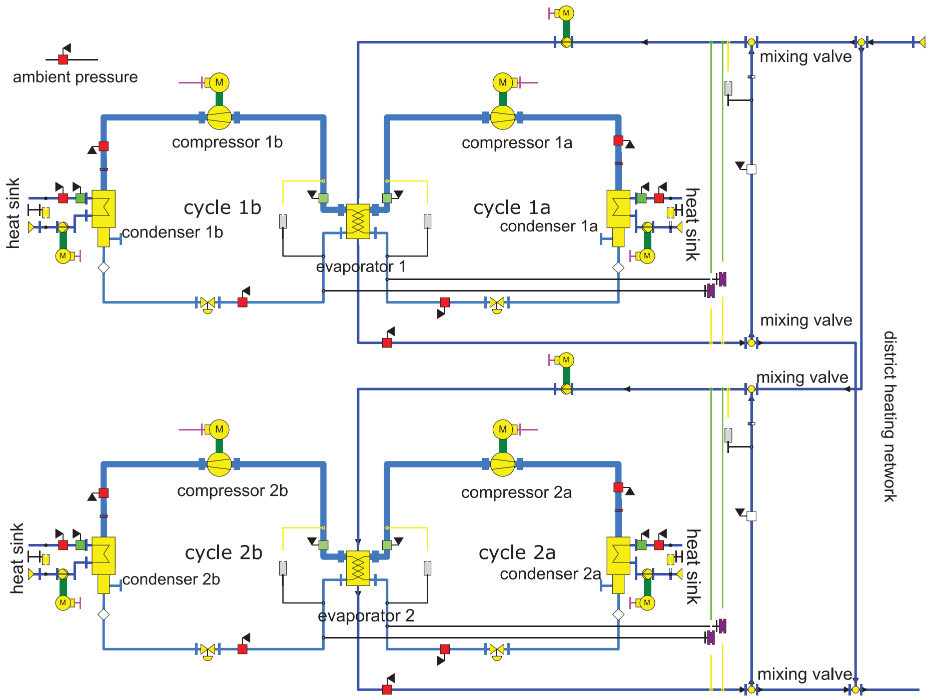

Figure 35.6: Heat pump variant b), EBSILON model.

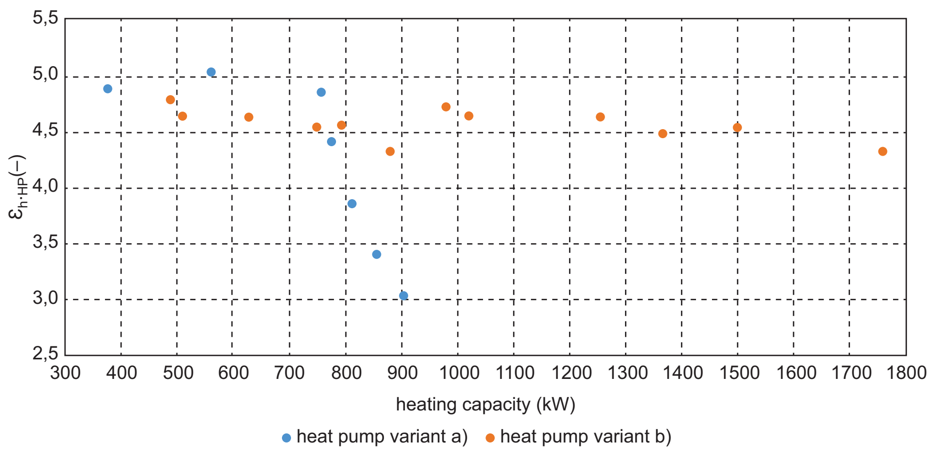

Figure 35.7: Coefficient of performance of heat pumps as a function of heating capacity, comparison of the simulated operating points of heat pump variant a) and b).

variant a) four heating capacity levels are selected and in variant b) five heating capacity levels are defined. The switching of the heat pump capacity levels can be controlled regarding the load forecasting as well as the availability of renewable electricity, with the storage tank charged or discharged accordingly. At the time when high loads are expected or when renewable electricity is available in large quantities, the heat pumps ramp up their heating capacity and charge the hot water store. Figures 35.8 and 35.9 show that variant a) requires a much larger storage capacity for peak load coverage than variant b). The COP of the respective heating capacity levels are summa-

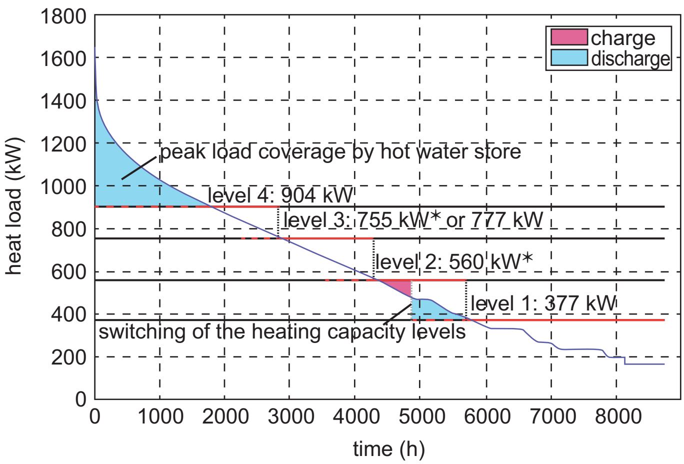

Figure 35.8: Principle diagram of heat pumps operation with the selected heating capacity levels, variant a).

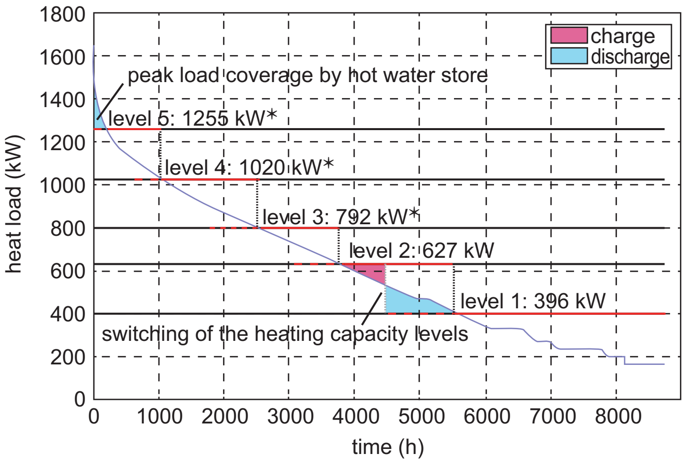

Figure 35.9: Principle diagram of heat pumps operation with the selected heating capacity levels, variant b).

Table 35.1: Simulated operating data of the selected heat pumps heating capacity levels, variants a) and b) (*: operating points only in winter).

	heating capacity levels	1	2*	3*	3	4
variant a)	$\dot{Q}_{h,tot}$ (kW)	376.92	560.37*	755.38*	776.59	904.16
	$\varepsilon_{h,HP}$ (-)	4.88	5.03	4.85	4.41	3.03
	heating capacity levels	**1**	**2**	**3***	**4***	**5***
variant b)	$\dot{Q}_{h,tot}$ (kW)	395.84	627.42	791.68*	1020.31*	1254.84*
	$\varepsilon_{h,HP}$ (-)	4.56	4.63	4.56	4.64	4.63

rized in Table 35.1. The heating load is above 750 kW during approx. 3,000 h per year. During this period, variant b) operates much more efficiently than variant a), resulting in a higher annual performance factor. The simulations of the system annual operations with the software TRNSYS show that with the heat pump variant b) higher annual COP is achieved than with the heat pump variant a). The annual COPs of variant a) and b) are 3.31 and 4.63.

35.4 System simulations with TRNSYS

The parameter studies using TRNSYS should show the influence of the two important variables, the nominal heating capacity of the heat pumps and the storage tank volume, on important evaluation variables. In order to ensure the comparability of the results, the course of the network heating load remains unchanged. When modeling the system using the TRNSYS program, the heat source has a constant temperature of 52 °C. The assumptions for the volume flow from Chapter 35.2 apply.

The heat pump model in TRNSYS is simplified with a cooler (evaporator) and a heater (condenser). Both components are coupled via the coefficient of performance. The coefficients of performance (cf. with Chapter 35.3, variant b)) were implemented as a function of the coefficient of performance for the entire operating range. In the simulations, an automatic design of further important parameters (e.g., feed pumps) is carried out. The control in the TRNSYS deck is based on a self-programmed type.

For the system evaluation, the heat pump coverage ratio f_{HP} (equation 35.1) is used. This is because the only heat generators in the heat supply system presented are the heat pumps. This equation takes into account the network load Q_{Net}, storage heat losses $Q_{St,loss}$ as well as the required reheating energy Q_{VH}, if there is an undersupply due to insufficient heat pump heating capacity.

$$f_{HP} = \left(1 - \frac{Q_{VH}}{Q_{Net} + Q_{St,loss}}\right) \cdot 100\ \% \tag{35.1}$$

Figure 35.10 shows the resulting curves of the heat pump coverage fraction f_{HP} over the heat pump heating capacity and the storage volume. It should be noted that a complete heat supply only exists with a coverage fraction f_{HP} of 100%. This area is marked with red color in Figure 35.10

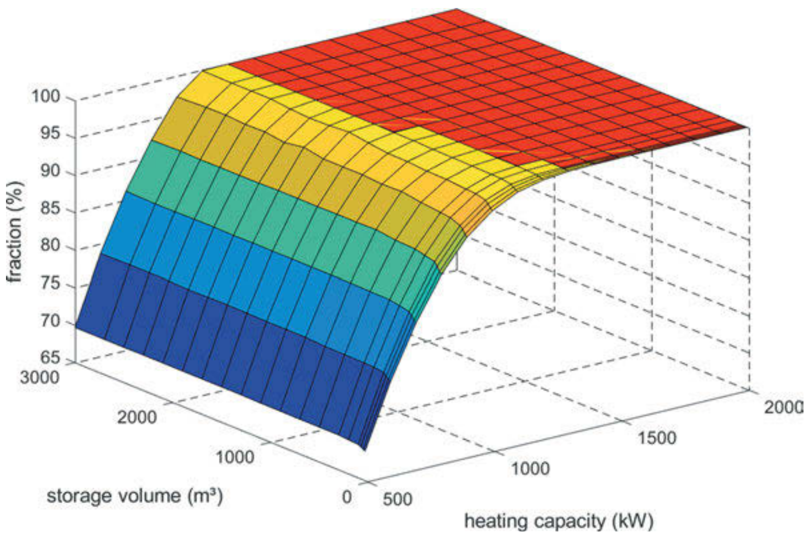

Figure 35.10: Influence of the heat pump heating capacity and the storage volume on the heat pump coverage ratio, detailed simulation with TRNSYS.

When high heat loads occur, the peak load is covered with the help of the hot water store (balancing between the heat pumps heating capacity and the network heating load). As shown in Figure 35.12, the use of hot water store leads to a reduction of the required heat pump heating capacity. For example, in the absence of the storage tank, the heat pumps have to cover the full peak load of about 1,600 kW. A small buffer storage ($V_{St} = 30\ m^3$) reduces the required heat pump heating capacity $\dot{Q}_{HP}$ to about 1,300 kW (about 18.7%). A larger storage tank of 200 m^3 minimizes the heating capacity $\dot{Q}_{HP}$ down to 1200 kW. Due to the course of the network load, a further increase of the storage volume V_{St} only leads to a further reduction of the heat pump heating capacity from 2,500 m^3. The lower heat pumps nominal heating capacity leads to lower electrical load.

In addition to the heat pump coverage ratio, low heat generation cost is another parameter for evaluating the economic viability. For this purpose, information to the investment costs is required. The basis for this are the specific costs (characteristic values or cost functions) from other projects and research, cf. z. e.g. with (Urbaneck/Oppelt/Shrestha 2014). Subsequent calculation of the heat generation costs is based on VDI 2067. (VDI 2012) According to the assumptions, the annuity factor is 6.51% (5% interest, 30 years technical life time for all components). For the present study, following assumptions for consumption-related costs apply, that the electricity price is 0.16 €/kWh and free use of the city district heating return flow (waste heat utilization).[8] Planning, land and development costs as well as value added tax, financial support and the CO_2 price are not taken into account. It should be noted at this point that these economic calculations do not claim to be complete. They are intended only as a comparison of present systems. Each project is unique. It always requires individual economic and technical verification.

The specific investment costs and the heat generation costs are shown in Figures 35.11 and 35.12. Only values are taken into account where the coverage fraction f_{HP} is 100% (to the right of the blue dashed line). Three points are marked in the diagrams:

1) The design without the hot water store (variant Ref_0, point L_{C0}) provides the reference values.
2) The point with the minimum costs (variant DV_1, L_{C1}) is defined here. This variant considers only the economic efficiency criterion.
3) Minimum costs with a storage volume of 1,500 m^3 (variant DV_2, L_{C2}) are defined with this variant. Here, in addition to economic efficiency, other aspects such as security of supply and increasing system flexibility (e.g., reaction to power surpluses) are taken into account. With this storage volume, it is possible to ensure the heat supply for about one day with relatively high network heating loads.

The curves of the isolines for the specific investment costs[9] $k_{\mathrm{I,\,spec}}$ in Figure 35.11 confirm that there is an economically optimal ratio between storage volume V_{St} and heat pump heating capacity $\dot{Q}_{\mathrm{HP}}$. The minimum heat generation costs k_{h} (Figure 35.12) are in principle in the lower left area of the diagram. Accordingly, the slimmest possible system dimensioning is economical for the current assumptions. The variant Ref_0 (point L_{C0}) has higher heat generation costs than the variant DV_1 (point L_{C1}), which has a small storage tank. Here the ground area of the district heat supply center $A_{\mathrm{G,\,EC}}$ has an effect. An increasing heat pump heating capacity requires more floor space. The heat generation costs of the variant DV_2 (point L_{C2}) are about 16% higher than those of the variant DV_1 (point L_{C1}).

Table 35.2 contains an overview of the system dimensions discussed. The key figures shown are suitable for a system comparison. Of all the variants shown in Table 35.2, variant DV_2 (point L_{C2}) offers the highest potential for subsequent optimization of operation. A larger hot water store allows a longer phase of heat preproduction while maintaining the most efficient operating points of the heat pumps and can additionally keep more heat in reserve. This also enables the exploitation of ecological and economic benefits when electricity is available at particularly low cost.

8 Internal project assumption.

9 Ratio of investment costs to annual network heat load. Increasing values indicate high specific investment costs.

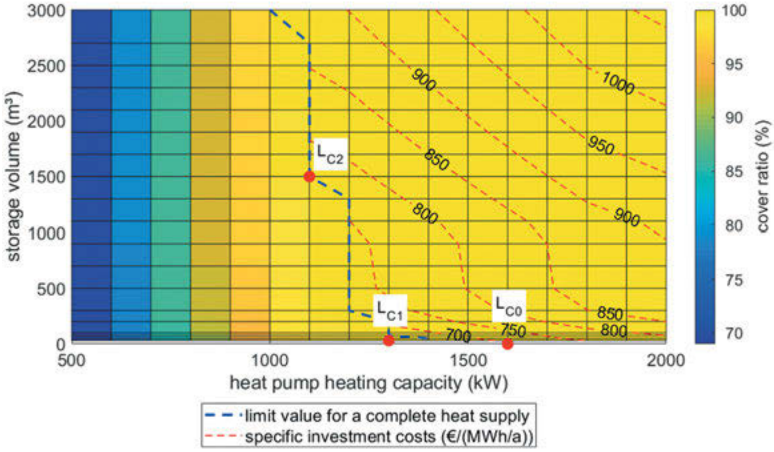

Figure 35.11: Specific investment costs for different system dimensions, detailed simulation with TRNSYS.

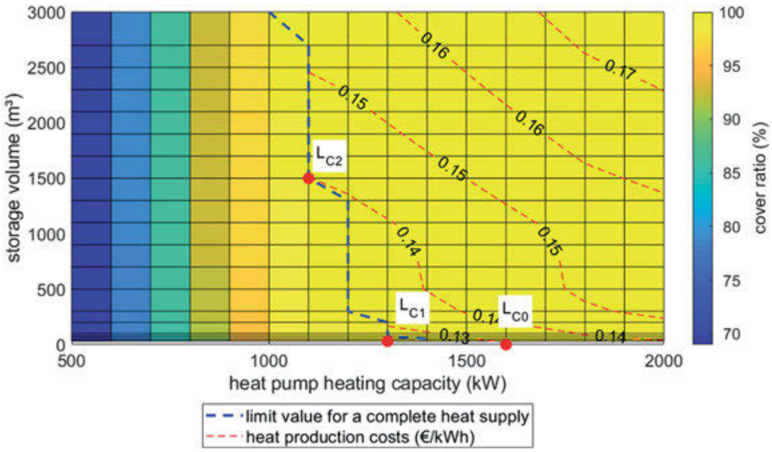

Figure 35.12: Heat production costs for different system dimensions, detailed simulation with TRNSYS.

Table 35.2: Overview concerning the points according to the specified criteria and ratios, detailed simulation with TRNSYS.

Point	$\dot{Q}_{HP}$	V_{St}	$A_{G,EC}$	k_h	$k_{I,spec}$	$\frac{\dot{Q}_{HP}}{V_{St}}$	$\frac{\dot{Q}_{HP}}{Q_{Net}}$	$\frac{\dot{Q}_{HP}}{A_{G,Q}}$
	(kW)	(m^3)	(m^2)	(€/kWh)	(€/(MWh/a))	(kW/m^3)	(kW/(MWh/a))	(kW/m^2)
L_{C0})	1,600	0	192	0.13	491	–	0.31	0.038
L_{C1})	1,300	30	134	0.12	640	43.33	0.25	0.031
L_{C2})	1,100	1,500	110	0.14	772	0.73	0.21	0.026

35.5 Summary and Outlook

In this work, a concept of the heat pumps and a hot water store local heating system with the use of a city district heating return flow as the heat source for low-emission local heating supply was presented and theoretically investigated. With the presented heating supply system, the implementation of a completely emission-free heat supply in residential districts is possible in principle while meeting the economic requirements. An important prerequisite for ensuring economic viability (cost-effective heat supply) is the lowest possible consumption costs for electricity and heat source. One of the assumptions was that the heat source is available free of charge.

The working fluid selection for heat pumps in local district heating systems in typical residential districts shows that the commercially available refrigerant R1234ze(E) possesses the best combination of thermodynamic, environmental and safety properties with low toxicity and flammability. The use of this refrigerant is feasible under the safety and environmental requirements of the relevant German and European regulations.

In order to comply with the boundary conditions in the district (e.g., limited availability of the heat source city district heating return flow), two heat pump cycles with different operating strategies were considered: a) standard heat pumps with mixing circuit and b) increasing the temperature spread in the evaporator. Results from the EBSILON-simulation show that variant b) covers a significantly larger capacity range compared to variant a) with two heat pumps. For heating capacities above 750 kW, the heat pumps of variant b) operate more efficiently than the heat pumps of variant a). Accordingly, the variant b) is more suitable for the Marienthal district (Zwickau, Germany), since a higher annual coefficient of performance is achieved for the given network heat load. From an economic point of view, the variant b) shows lower investments for the required nominal heating capacity, since variant a) requires additional machines and more complex hydraulic circuits.

The parameter studies carried out with TRNSYS have shown that many system designs meet the heat supply requirements. A relatively small hot water store volume of 30 m^3 significantly reduces the required heating capacity of heat pumps and enables the optimization of the heat pumps operation. To ensure the supply reliability, a hot water store volume of at least 1,500 m^3 is recommended.

The scaling of the results will later allow the findings to be transferred to other residential districts. The measures to reduce the supply temperatures in summer can be verified. In addition to the heat supply of urban districts, the concept of the heat pumps and heat storage system also offers a high potential for heat supply in industry, commercial buildings, institute buildings, etc. In many industrial sectors, such as the pharmaceutical and automotive industries, the processes require constant cooling, so that a relatively large amount of waste heat has to be dissipated. Here, the use of heat pumps and heat storage systems offers an energy-efficient and economical solution for the simultaneous heating and cooling supply.

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Daniel Kretz, Tobias Teich, Daniel Franke, Manoël Kraus, Oliver Scharf, Sebastian Junghans, Tim Neumann

36 Interconnection of Smart Homes and Smart Buildings as a Building Block of Smart Cities

Summary: An increasing digital interconnection of commercial and residential buildings is an important element to achieve a more and more energy efficient control by communication and automation. It provides a significant approach to fight climate change and increasing energy prices in a cost-effective manner with low initial investment. Besides potential energy saving for inherent amortization, automation solutions and resulting communication infrastructures allow us to establish innovative digital services and new points of intersection. Another aspect of smart buildings is the matter of fact, that systems are getting more and more complicated, error-prone and challenging during planning, implementation, maintenance and more general the entire management and lifecycle process. During the last years we have developed an automation platform with standard and open-source components including configuration generating processes to efficiently build up infrastructure for a digital heating community in apartment houses. The resulting information and communication infrastructure between smart homes and smart buildings opens up a nearly undiscovered field of interconnection beyond individual internet access of the inhabitants and an important opportunity to provide innovative digital services based on this. Therefore, we are going to provide an additional insight for example into our latest implemented services that go hand in hand like an emergency call service and automatic analysis of heartbeats as well as a rental system for micro mobiles.

36.1 Introduction

Nowadays, the achievement of energy savings and simultaneously increasing comfort and security in buildings by implementingcommunication and automation systems is a matter of fact. (e.g., Wisser 2018, Naumann/Christian/Göttert et al. 2016, Teich/Hoffmann/Igel 2015, Aschendorf 2014) Because of a significant demand and hence the highest consumption part of heating energy in living areas, we find an enormous energy saving potential when addressing thermal room energy as well es the energy supply and delivery of heating systems within multi-family houses. In long term, any energy savings

Daniel Kretz, Tobias Teich, Daniel Franke, Manoël Kraus, Oliver Scharf, Sebastian Junghans, Tim Neumann, Westsächsische Hochschule Zwickau, Germany

https://doi.org/10.1515/9783110777567-036

effect will play an import role to refinancing the required technical investment in smart automation components. Any motivation about energy savings and carbon dioxide reduction as fundamental elements against climate change are laudable but it is also a matter of fact that priority questions from real estate companies and landlords are about accruing costs and financing of innovative solutions. Especially when confronted with heating costs accounting, those questions are anything but trivial to answer because resulting costs are allocated directly to the final consumer. Hence consumers will become the only profiting party, but without paying any direct contribution to refinancing on invested technology. (Pachowsky 2018) Consequently, in future we need more and more creative and innovative operator models, like accounting a more stable thermal energy price but keep cost savings for refinancing. Beside this financial aspect, a systematic and comprehensive development of information technology and communication systems provided and required by automation solutions and interconnection play an important role. Implemented smart homes and their internal connection to smart buildings provide a new solid foundation for developing and creating smart city districts independent from the public internet connection of residents. (Magnaghi/Flambard/Mancini et al. 2021) In the long term it provides an additional opportunity to connect regional and trans-regional service providers or suppliers in urban and rural areas to strengthen local economy and giving easier access to their services.

Especially providing an existing communication infrastructure allows the creation and establishment of innovative value-added services to smart city inhabitants in a comfortable way. Consequently, it may support refinancing of implemented smart components and network infrastructure by third parties and hence achieving additional benefits for any involved actor. Important requirements are decentralized structures, clearly defined communication services and data structures as well as interfaces with defined processing workflows to guarantee privacy, data protection and reliability.

36.2 Smart Heating Community

Initial energy saving effects of a single flat in an apartment building result from preventing unwanted leaks of energy and circumventing temperatures in beyond higher comfort areas. By defining reasonable temperature ranges and appropriate setback values as well as adapted heating time periods we already achieve basic savings in a very scalable solution. Regular events like scheduled absence periods and the daily user behavior can be adapted either directly or indirectly (e. g. smart locking system) by user defined, comfortable heating periods and adequate setback periods. Random but energetic relevant events like spontaneous long-term absence or leaks of energy, like open windows and other energy sinks, may be communicated or recognized and finally processed by the automation system. Studies show that about 15 percent of the events with very high energy transfer are responsible for about 55 percent of total energy output.

Consequently, it is crucial to evaluate the energetic situation continuously to avoid ineffective or wasteful energy output situations. Allowing for a prevention of defined excessive temperature areas an energy savings potential of between 20 and 25 percent can already be demonstrated by the systematic implementation of smart home automation heating systems. (Schröder/Papert/Teich et al. 2018) Furthermore, it is necessary to collect and summarize information about real thermal energy demand over all flats. Nowadays it is most commonly state of the art to operate heating systems using a weather-driven control. (Hesse 2020) That means, a heating system uses a measured outside temperature value to calculate the required flow temperature for the heating circuit. Therefore, the outside temperature is used as a parameter for a heating curve function. Additional parameters that may be configured by the operator are either steepness (S) or parallel shift (K) of the curve to adapt a heating system on the building conditions (Figure 36.1: Heating curve). In fact, there is not any evaluation whether those parameters and the resulting heating curve fit a real thermal energy demand for any outside temperature value on any time because there is no feedback loop included in the heating system. Normally those parameters include plenty security headroom to ensure a sufficient supply and necessary flow temperature at the furthest heater within a circuit. Hydraulic balancing may be another important aspect to consider for efficient thermal energy transfer, that shall be mentioned only for the sake of completeness.

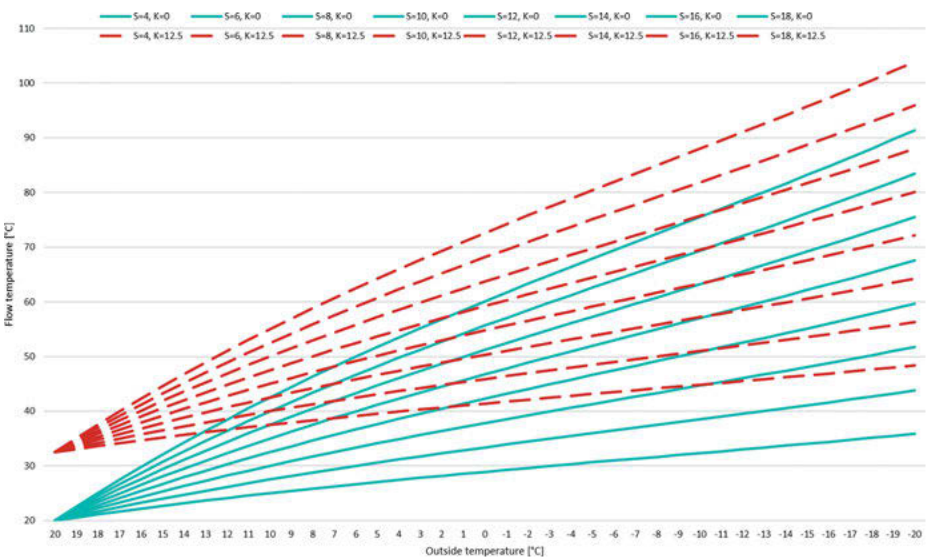

Figure 36.1: Heating curve.

Objectively, the significant benefit of high flow temperatures is a faster modification speed of room temperature and subjectively a sensible radiant heat next to the radiator. Otherwise, there are obvious multiple disadvantages of higher flow temperatures like thermostats blocking the flow most of the time especially during seasonal transition time and there are higher transmission losses in the piping system. Additionally, the efficiency of a heating system is getting increasingly worse with higher flow temperature so that regenerative approaches like installing geothermal heat pumps are getting increasingly unattractive. Strictly speaking, touching a radiator with e. g. 30° C suggests a “cold” feeling because of a normal body temperature above 36° C. Relative to a given room temperature of 21° C, over a defined period, we have a continuous thermal energy output. An approach to determine the real demand has already been described by (Baumgarth 1991). He describes a basic algorithm to calculate the current thermal heating flow temperature demand evaluating the current valve positions as a demand indicator. Thus, a heating system’s weather-based control can be replaced by an efficient demand-driven regulation. Put simply, the objective of this approach is to force valve positions of demanding rooms between a positioning of 70 to 90 percent. A heating system may decrease the current flow temperature if valve position values are below the lower border. Otherwise, if we pass the upper boarder, a heating system’s flow temperature may be increased. Additionally, this approach may be combined with a classic weather-based control heating curve to decrease or increase a calculated delta value e. g. within given bounds. For this approach it is essential to implement automation solutions and create a complete heating information network to regulate and control valves within each room and collect these position values within the building to adapt the heating system parameters driven by demand automatically.

36.3 Multi-Service-Platform

Resulting from various research projects executed by the University of Applied Sciences in Zwickau, especially “Low Energy Living (LEL)” and “Ambient Assisted Living in Controlled Environments” (A^2LICE) we initiated the development of a more flexible and scalable hardware and software platform with the objective to create fundamental communication and automation nodes for smart buildings and smart districts in the future. (Leonhardt/Neumann/Kretz et al. 2018) Development has been focused especially on simplifying and minimizing configuration and initial operation process for field implementation and to maximize automation in this stage for a highly scalable serial product. The initial scope of functions has been limited on the heating control system scenario to focus the initially mentioned high potential for energy savings with regard to an efficient way for refinancing required hardware components. Another important aspect in this context is resulting from the corporative development with Metrona Union GmbH as a research and development company of several BRUNATA houses because they already provide measuring services and a very huge sensor network in Germany. Their heat cost allocators, which are installed on many heaters, have the primary task to measure the energy output of heaters for further accounting. Within a patented procedure (EP 3009908 and EP 3035144) those devices have been enlarged and got advanced functionality to enable room heating control and advanced algorithms for efficient calculation of room- and heater temperatures or to detect open windows without additional sensor installation. (Schröder/Papert/Teich et al. 2016, Teich/Kretz/Scharf et al. 2016)

Our developed hardware platform consists of a system on module developed by Toradex (NXP i.MX6) as a full-featured dual- or quadcore computer with a 32-bit ARM architecture. To provide necessary field bus access as well as input and output interfaces we have developed a custom carrier board to connect bus systems for communication, control, and regulation in the field of smart automation (Figure 36.2). These include e. g. ethernet network, USB (Universal Serial Bus) and CAN (Controller Area Network) interface, RS485 and UART (Universal Asynchronous Receiver Transmitter) for serial communication and 1-Wire e. g. for various sensors and actuators of heating systems and circuits. Additionally, our carrier board provides extension sockets to plug in extension boards e. g. with EnOcean radio transceiver. Depending on operational scenarios we can develop various carrier boards providing task specific interfaces. Currently, we designed a compound solution for smart home applications as well as for smart building applications and services. During several hundred installations in laboratory and field areas we had to recognize that a lot of interfaces remain unused. Therefore, we are going to separate and develop specialized boards for smart home and smart buildings with different assembly configurations in future versions.

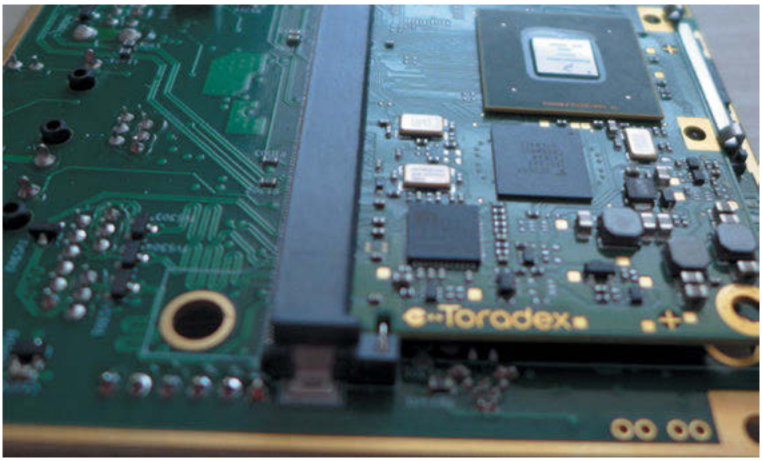

Figure 36.2: SOM with carrier board.

For this hardware platform we have created an individual operating system based on Linux using Open Embedded components with Yocto project to create a tiny system with low memory consumption and small processor usage. (Vaduva/Gonzalez/

Simmonds 2016) Especially for networking we have included necessary services for secured connection in context of smart home, smart building, and smart city districts. Therefore, we utilize services like firewall and packet filtering, virtual private network and secure shell host for encrypted and secured communication and maintenance. Additionally, we support flexible connection scenarios using either the provided ethernet interfaces or plug in additional wireless adapters using the USB interface. Our operating system and configuration tools support parallel utilization as wireless station or access points using a suitable adapter. Thus, we have achieved reduced hardware costs and port allocation. Especially for the digital coverage of inhabited properties, wireless solutions are essentially required for a minimal invasive retrofitting. Our primary paradigm is to provide certificate-based VPN channels to create secure connection internally as well as externally of smart homes and smart building to avoid publicly accessible services under any circumstances. Furthermore, we have developed a specialized configuration toolkit that supports a completely automated set up and configuration. Required configuration files are generated from custom workflow definitions that contain a required project description. With this approach we can set up hundreds of devices, flats and buildings, within a common infrastructure in shortest time. Precondition for efficient implementation are projects with template-based configurations and parameterization abilities based on dynamic workflow descriptions as we find in multi-family houses with identical or comparable technical equipment and functional scenarios (Figure 36.3). Workflows may be designed with parameters to customize project specifics artefacts or they may be bundled in separate generator workflows to create reusable project workflow templates. An important source of information to run through the generation process is a description file containing a digital twin of the building, flats, equipment to install and scenario specific parameters. Necessary information can be extracted directly from enhanced 3D models developed with building information modeling (BIM) standards with specified information requirements as well as using defined BIM objects. Using this approach, we generate not only the configuration files for our automation platform, but also the configuration for various administrative tools for support and maintenance of the resulting infrastructure as well as associated services. These include configuration of a domain name service (DNS), security policies, connection and authentication certificates for VPN communication, remote management tools or the generation of dashboards and required databases to analyze and monitor infrastructure and system interaction.

Based on this foundation, we can develop and design value-adding services and automation solutions in a highly modular manner. Required services like databases, web proxies, monitoring dashboards etc. are deployed as microservices via a separately generated maintenance infrastructure and service providers like update repositories and additional packet management tools or e.g., Docker container registries. (Grubor 2017) Furthermore, individual software components to implement a heating system network including individual room and heating system control, has been realized as a JAVA based OSGi (Open Services Gateway initiative) application that it can be deployed and installed either via packet management or Docker container. Using

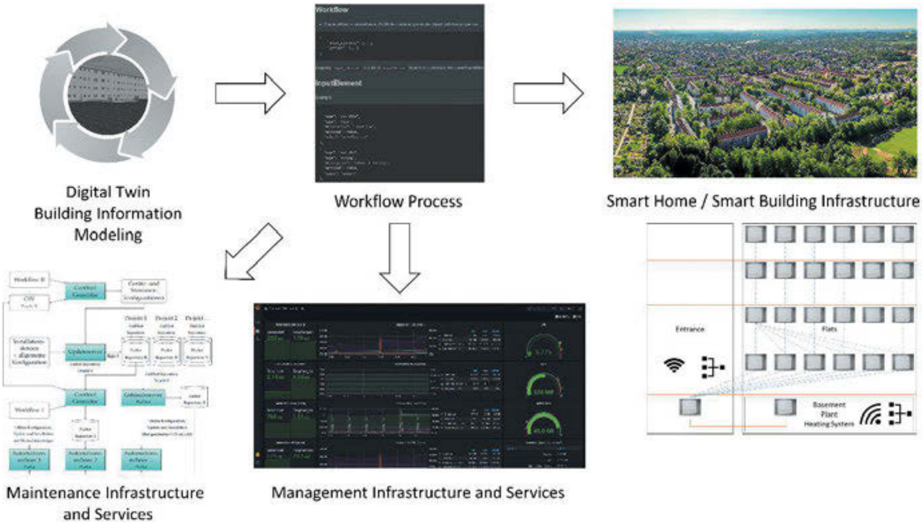

Figure 36.3: Generated infrastructure.

the OSGi standard specification, enables further service orientation because individual product definitions support a dynamic composition of application modules (bundles and features). Available interfaces, services, layouts, and applications can be customized for each project and delivered by the given service and maintenance infrastructure. Finally, we have developed a web-based dynamic and responsive user interface application that represents the result of application services and dynamic application of generated configuration files (Figure 36.4).

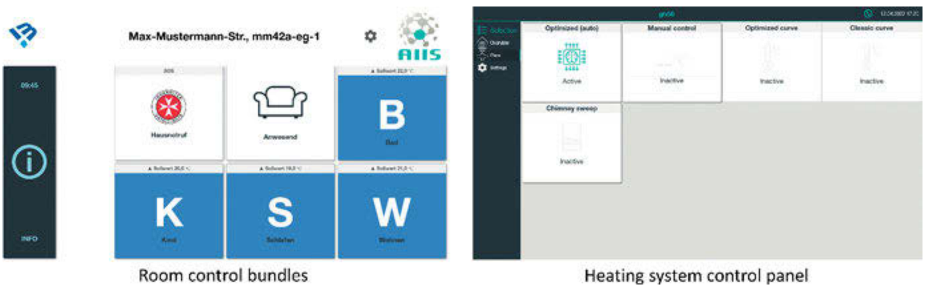

Figure 36.4: Variable product composition (UI).

If we want the interaction of different communication nodes within our network, we can include bundles for REST communcation (Representational State Transfer) or provide services to permanently store meta and logging data e. g. in a common database. Independent of the final product configuration, a decisive factor is to avoid configuration efforts of individual devices in the field whenever possible. Required customizing parameters need to be extracted from a digital twin or project specific description and shall be enriched by specific generator modules. In this way, we could massively reduce initial efforts during set up and configuration phase and hence minimize manual error rate to an absolute minimum. Errors in the workflow or template design ensure that all nodes in the network have the same problems in a reproducible manner. These can be fixed easily by generating updates that are automatically distributed and hence can easily be eliminated in bulk. Using this approach, we have implemented several living labs, distributed within the entire federal republic e. g. in cities like Borna, Jena, Hamburg, Cologne, Munich and Zwickau with round about 500 flats or offices and many thousands of peripheral devices and finally prepared the ground and added fundamental pieces for smart city districts. Especially in Zwickau we implement advanced infrastructure services for smart thermal grids in the research project ZED – "Zwickauer Energiewende Demonstrieren". (Leonhardt/Höhne/Neumann et al. 2018, Werner/Leonhardt/Höhne 2020) Additionally, in Jena the research project JenErgieReal is building on resulting infrastructures and the presented MSP. (Leonhardt/Teich/Bodach et al. 2020)

36.4 Application Module – Emergency Call Service

Because of the increasing number of elderly people (UN 2017a), as well as the lack of people working in the health care sector (UN 2017b), non-residential nursing care is becoming increasingly important. To enable non-residential nursing, it is beneficial to submit emergency calls (ER) from within the apartment. This is currently done by installing a physical button somewhere within the apartment which requires direct action of the inhabitant. Additionally, the developed automation platform offers a software button (Figure 36.5), as well as automated detection of unusual, potentially harmful behavior.

Figure 36.5: Emergency call process (UI stages).

Figures 36.5 and 36.6 show a simplified version of the submission of an ER based on the real-world process of our MSP submitting an ER to the Emergency Operations Center of the Johanniter-Unfall-Hilfe e.V. (JUH) where the ER will be processed by an operator at any time, optionally receiving your current location if not at home.

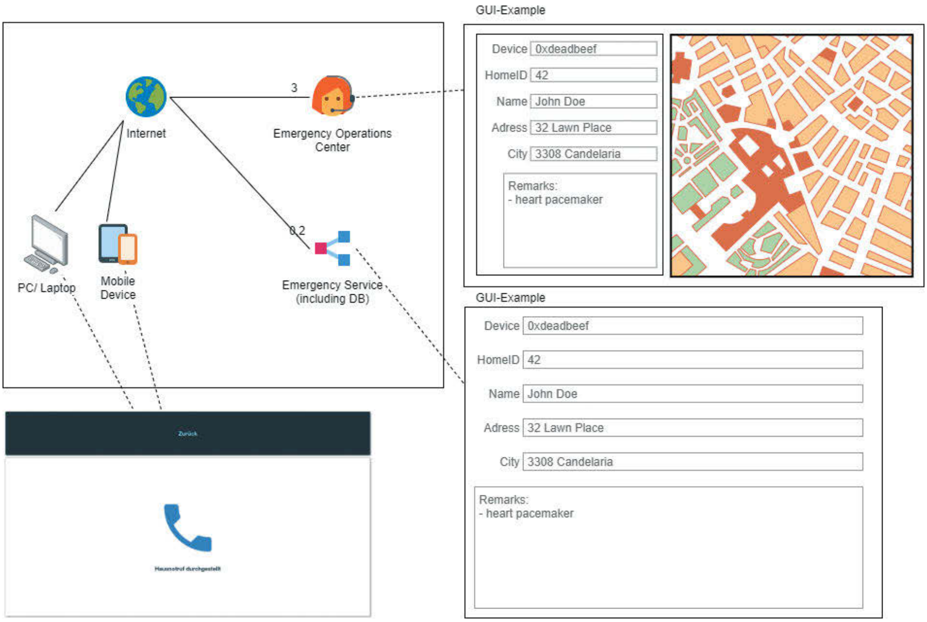

Figure 36.6: Emergency call service.

Prior projects like A^2LICE (Ambient Assisted Living in Controlled Environments, Teich/Hoffmann/Igel (2015)) showed that there are concepts from the health care sector, like activities of daily living, that are detectable by a digitalized environment and therefore may be used to detect unusual, possibly harming situations and conditions. For example, if an elderly inhabitant is detected to be present in the apartment but did not change rooms or at least go to the bathroom within the last 24 hours. It therefore is possible to automatically detect (potentially) life-threatening situations and run an escalation routine accordingly. This includes calling for emergency, but also, for example, informing/calling for family members or neighbors.

Furthermore, the platform can analyze locally available data about the living behavior of the inhabitant and inform or alarm him about certain conditions and, if desirable, make an appointment with the family doctor or next medical doctor. In a next step this local information could be made available to the nursing as well as ambulance service or medical doctors to gain more insights on the current health state of the habitant and therefore increase the quality of provided medical services.

In conclusion, the emergency call feature is just a first step towards the enablement of health care services that will decrease the workload of employees working in the non-residential nursing care as well as enabling inhabitants to live longer in their accustomed, desired living environment.

36.5 Application Module – Electrocardiogram

Until now, analysis of electrocardiogram recordings could be applied in clinical or ambulant environments with trained persons and required expert staff in this medical sector. Since the availability of smart watches, the recording port and basic automatic analysis of electrocardiograms (ECGs), parts of this check-up could be integrated into home environment. In fact, the current ECG evaluation functionality of smart watches is very limited. Further application modules of our MSP supply artificial intelligence (AI) algorithms to enhance existing ECG evaluation of smart watches with advanced diagnoses. Additionally, we could improve the accuracy of sinus rhythm detection against the smart watch algorithms and our solution includes the interpretation of pediatric smart watch ECGs of children. We have developed a visualization module to support ECG in our dynamic front-end application with the precision of printed ECGs in clinical application areas. This supports verification and view of results by medical personal. Furthermore, there is also interactive functionality implemented, e. g. measurement of distances inside the electrocardiogram view. AI detected results are recorded into the ECG to check and evaluate these as well as resulting diagnoses. Therefore, AI diagnoses are printed directly into the ECG view within the diagnosis relevant position. Our ECG evaluation is implemented using Convolutional Neural Networks (CNN) (Jun/Nguyen/Kang et al. 2018, Moody/Mark 2001). CNNs are used for image processing and recognition as well as image classification. For an automated evaluation of ECGs our AI modules extract singular pulses and classify them. To teach a CNN AI model we need a huge amount of training data. Training data has been provided in comma-separated value (CSV) files from an apple watch. These CSV files contain digitized measurements of an analogous ECG signal. For further processing, we had to translate those unidimensional EGC signals into multiple single frames using an image segmenter. Therefore, a segmenter receives digital sensor values of ECG export values and a digitization rate. The output provides indices of our measurement values with R-R peaks (heartbeat – maximum amplitude, Figure 36.7). Using these indices values we can divide ECG values automatically into single frames to group given training data into classes and finally train our AI model. Each class defines a possible heartbeat that may be found within ECGs. Classes define e.g., pulse or beats on normal level, right or left bundle branch block as well as a pacemaker stroke. More complex training and detailed classification data improves the resulting diagnosis quality. Within our developed MSP we can integrate AI models and provide custom application programming interfaces or user interaction modules with appropriate visualization and diagnostic views. Recorded user data can be exported easily for further processing and AI diagnosis. Additional parameters like ECG diagnoses and age of recorded person support further analysis using the implemented domain specific medical knowledge of these MSP application bundles.

The integration of an AI based ECG evaluation and diagnosis module provides an easy integration into daily living and future ability to implement event driven care services within connected smart buildings. Secondary prevention by early disease detection may also reduce costs in the healthcare sector. To treat a disease by early recognition is usually easier than after their manifestation. Required diagnostic process e.g., recognition of cardiac arrhythmia using electrocardiogram is usually done in medical facilities because of required infrastructure, devices, and staff and consequently this process becomes expensive and cost intensive. Integrating this service provides a basis for innovative health services for elderly but also younger people beyond the medical area. Especially diagnostic algorithms for children providing acceptable results were missing. Especially in younger age there is a demand because cardiac arrhythmia is not uncommon in childhood, but a diagnosis is usually difficult because of paroxysmal events. This disease may also suspend during a year and hence repeated recording is required. Using smart watches this process can be established and integrated in the home area with smart connections and evaluation services. Existing smart home technology supports this process and the advanced AI algorithms support pre-diagnosis and may be combined e.g., with the emergency call service in future releases.

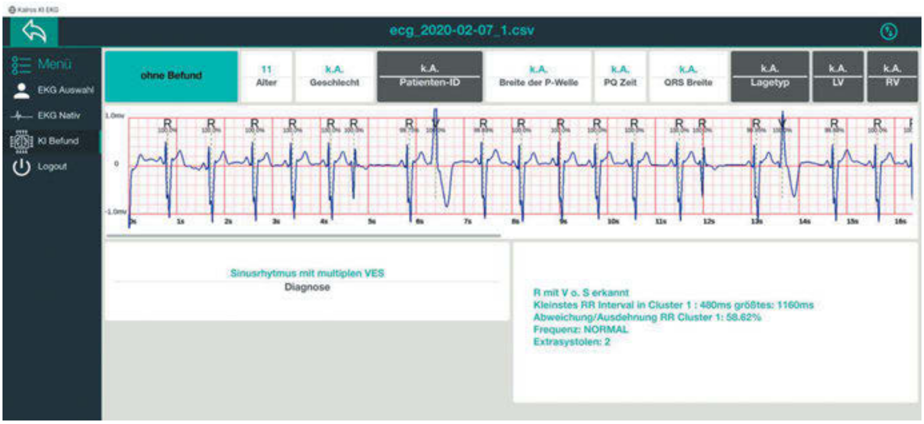

Figure 36.7: ECG visualization module and AI diagnosis results.

36.6 Application Module – Mobility Service

The mobility station in Zwickau was created as part of the ZED project and offers residents in the district, a lending service for electric scooters and cargo bikes. The offer is intended particularly for people who are often dependent on help in everyday life, for example to go shopping or to the doctor. The project enjoys solid support and regular use. The mobility station has an office, which is supervised with fixed opening hours from Monday to Friday. Next to it, we provide an additional autonomous lending station that is always accessible via RFID cards. This gives users a way of independently lending vehicles after office hours and weekends. This so-called mobile box is currently in its first prototype phase. It offers space for one e-scooter, charger, and the electronic lending system. The lending process is controlled by an embedded computer. The software for the system was further developed based on the multi-service platform (MSP). It uses its core components and is expanded with an adapted user interface which enables users to start and end lending processes via touch display (Figure 36.8).

Figure 36.8: User interface scooter checkout.

The current prototype phase is intended to collect initial user feedback for future developments. Right now, it is limited to a single e-scooter and a reduced group of users but targeted expand to more stations and a larger user group in the next phase. The current feedback shows that, an important feature for further development should be a reservation option. This offers further opportunities to utilize the MSP. In apartments, a mobility service could be offered as a supplement to heating control. The status of the mobile box can be called up to see whether and how many e-scooters are available nearby and to reserve them if necessary. The mobility concept in its entirety and the accompanying services present new perspectives, to bind their residents to the smart city district in the long term and to keep the facilities livable and lively into old age (Figure 36.9).

Figure 36.9: MOBIL BOX – autonomous rental station.

36.7 Conclusion

In this chapter we provided a small insight into our development efforts of our Multi-Service-Platform. The initial motivation was triggered by the objective to create a highly scalable product that is also suitable for mass configuration and installation. Therefore, we gave a broader technical overview about the created system to get an idea about its potential expandability. Our development basically started with an automation solution for heating control and demand driven heating system adjustment. As we have already shown in Zwickau-Marienthal, using the valve position algorithm of Baumgarth, we can save up to 25 percent primary energy input that scales up in our example to a saving value round about 10.000 € yearly for four connected multi-family houses. (Teich/Hoffmann/Igel 2015) This amount could be initially used for amortization of required technical investments but this requires sophisticated cash flows. In fact, we could develop a cost-minimized solution because of reusing existing sensor networks like heat cost allocators for temperature measurement in each room. Our developed hard- and software solution provides much more power and this scenario is technically seen very lightweight. Because of resulting networks for inhabitant interaction, it is possible to develop and install new services that bring together local suppliers, service providers and inhabitants. This in mind, we can achieve a long-term win-win situation for all participants in this restricted local service network. Our currently developed application scenarios like emergency call service, electrocardiogram and a rental station service for micro mobiles provided a tiny example, how our platform currently grows and interconnects to various digital services in the neighborhood of our near future.

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Lukas Wechselberger, Benny Gottschalk, Mirko Bodach

37 Forecast-Based Storage Control at Quarter Level

Summary: In future residential quarters, it will no longer be possible to make a clear distinction between the individual sectors. Already today, the energy exchange between the subareas, such as electricity, mobility and heat, takes place smoothly with electrical energy as a connecting factor. Regarding climate change and the associated shift away from fossil fuels, the demand for electrical energy will increase in the future. The example of the project "ZED (Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau's Energy Transition)" shows the importance that heat pumps already have today in supplying entire districts. To be able to guarantee the resulting demand for electrical energy, energy storage systems will play an increasingly important role in addition to the expansion of renewable power plants. However, these must be operated intelligently, i.e. forecasting methods are becoming increasingly relevant for the required energy storage control in order to be able to use the storage ideally. In this way, it can be ensured that charging and discharging processes are always carried out when there is either a power demand in the connected grid due to a high consumer load or a power surplus due to a correspondingly high generation. This chapter will outline how such a forecast must be set up and adapted to be used for electrical storage at neighbourhood level.

37.1 Introduction

The energy demand is constantly increasing due to the progressive sector coupling in our energy system. When fossil fuels such as oil, gas and coal disappear, the demand for electricity will not only increase in the electricity sector. In the future, alternatives for heat supply and mobility need to be found. Furthermore, the demand for electrical energy storage will also increase due to the growing number of renewable power plants, as these do not guarantee a constant supply of electrical energy, but rather operate depending on solar radiation and wind strength. The necessary control and switching intelligence are only available at the higher voltage levels, but not at the low-voltage level and only partially at the medium-voltage level. Many components are needed to make the smart grid controllable and switchable down to the low-voltage level in the future. (Hempel/Dziurzik/Bodach 2020)

Lukas Wechselberger, **Benny Gottschalk**, **Mirko Bodach**, Westsächsische Hochschule Zwickau, Germany

https://doi.org/10.1515/9783110777567-037

However, since renewable power plants are not capable of handling base loads and have highly fluctuating generation, future energy storage systems must be operated in such a way that they can always balance the required energy demands and surpluses. For this purpose, it is becoming increasingly important to collect all relevant measurement data with the highest possible resolution, for example, to be able to control a quarter storage system accordingly. Photovoltaic systems, which are increasingly being installed on single-family and multi-family houses, but also on apartment blocks, are an example of an increasing number of renewable power plants, especially in the low-voltage network. (Leonhardt/Höhne/Neumann et al. 2018) In most cases, the aim of a private photovoltaic system is to achieve a high degree of self-sufficiency. In order to be able to achieve this goal, more and more photovoltaic systems are being equipped with the "electricity storage systems" available on the market. (Sterner/Stadler 2017) Due to the high cost pressure, most home storage systems have relatively small storage capacities. Therefore, a complete storage cycle of the system is done on almost every day in order to offer the end consumer the greatest possible return on investment. The storage systems work according to the principle of zero regulation at the grid transfer point, i.e. as soon as the photovoltaic system converts enough energy to feed into the upstream grid, the storage management system tries to counteract this by presetting the charging power. In the opposite case, the system tries to counteract an energy draw from the grid with the previously stored energy until the energy storage system is completely discharged. For the private user, this is a very simple and practical regulation. In the future, additional loads will be added to the general consumption of a household in the form of charging stations and heat pumps. These must also be considered when operating electrical storage systems. To be able to efficiently reduce the resulting load jumps and load peaks without having to reduce the degree of self-sufficiency or self-consumption, an intelligent, proactive control of the energy storage system is necessary. However, this requires knowing when and how much power is produced by the photovoltaic system and simultaneously used by the consumers. Therefore, a reliable load and photovoltaic forecast is necessary. (Sterner/Stadler 2017) In the following chapters, a procedure will be presented that can be used to forecast the general consumer demand. Based on this, it shall be demonstrated how this procedure must be expanded to be able to be used across sectors.

37.2 Initial Situation

In the following calculation, a measuring point is to be considered at which two blocks of flats with a daily average consumption of approx. 400 kWh in winter and approx. 320 kWh in summer are located. At this measuring point, the consumer demand is to be queried every second, stored in a database and processed later. Due to the high number of measuring points in the quarter and the resulting large data volume of over 250 measured values with an average sampling time of 3 seconds, communication difficulties occur at times. The exact systematics of these measurement incidents cannot be precisely narrowed down due to the very high data volume, but they can be traced back to the transmission via Powerline. This means that no usable measured values are available during these periods. This must be considered when preparing the forecast in order to make it more robust against possible interference.

A photovoltaic system is installed on the roofs of each of the residential complexes, which together have a peak output of 62 kWp. Of the photovoltaic systems, a single system is recorded directly by a measuring system. The second system can be calculated from three other photovoltaic systems measured in the quarter, which have a similar orientation as reference measurements. The energy storage system used, which is located in one of the investigated apartment blocks and acts on the measurement output, was dimensioned with a capacity of 9 kWh and a maximum charging and discharging power of 12 kW. For this reason, a larger storage unit is simulated in the development of the storage management to examine the potential of the storage management.

37.3 Overview of Load Forecasting

There are different forecasting methods to "predict" electrical loads. Most of the forecasting methods described in the literature are not applied to the load forecasting of individual households, but to a large number of consumers. A regression analysis can be used to make a specific forecast. Historical data is the basis for the calculation and determination of the coefficients or the function. A large data base of different measured values, which have an influence on the load process, is necessary to achieve the best possible results with this type of forecast. (Gobmaier/Mauch/Beer et al. 2012) Another possibility to forecast electrical loads is the use of neural networks. However, these are very complex, computationally intensive and therefore also cost-intensive. (Bocklisch 2009) However, a less complex forecasting method can also deliver very precise values if it is designed correctly. For this reason, the focus of this chapter is on resource-saving methods.

A procedure must be developed which it is possible to classify the results after calculating a forecast run. In this way, decisions made during the development of a procedure can be visualised in a comprehensible way and the results become comparable.

To be able to compare the quality of the forecast, there are different types of error calculation, which, however, do not all have the same significance for a forecast. The quality of a forecast method is only meaningful if a comparison between the forecast and the actual measured value is possible.

To assess the quality, the mean absolute percentage error (MAPE) and the median absolute percentage error (MdAPE) over a period of 4 weeks of the different forecast types are examined. These can be calculated according to equation 37.1 and equation

37.2. If the mean absolute percentage error of a forecast type were equal to zero, this would mean that an exact forecast would be available. Various studies have already shown that a forecast with a mean absolute percentage error of up to 10% can still be considered sufficiently accurate under similar conditions. This means that the predicted values reflect reality on a scale that is sufficient for further processing without loss of quality. (Höft 2004)

$$MAPE = 100\% \cdot \frac{1}{T}\sum_{t=1}^{T}\frac{|x_t - y_t|}{y_t} \tag{37.1}$$

$$MdAPE = 100\% \cdot Median\left(\frac{|x_t - y_t|}{y_t}\right) \tag{37.2}$$

y_t . . . observation occurred at time t
x_t . . . forecast available at the time t
T . . . total number of forecasts available (Barrot 2009)

With the help of these calculations, the values obtained in the load forecasting can be examined and the quality of the chosen forecasting method can be assessed.

37.4 Creation of the Load Forecasting

A “day ahead forecast” is used as the initial position for this resource-saving and quick-to-implement forecasting procedure. This procedure is a very simple method in which the measured value of the power of the previous day serves as the forecast value for the following day. When sampled at 15-minute intervals, the power value of the forecast according to equation 37.3 corresponds exactly to the measured value 96 time steps ago.

$$\frac{60\ min \cdot 24\ h}{15\ min} = 96 \qquad x_t = y_{t-96} \tag{37.3}$$

Since the measuring system records every second, average values are created from the measured values recorded within 15 minutes. Since it can happen that no measured values are available within this interval due to measurement failures, a backup must be set up for this. This provides that if a power value is not available in the quarter-hourly cycle, the average value is calculated from the previous and the subsequent measured value. If the following values cannot be determined either, e.g. due to a longer measurement failure, the averaging is continued with the respective correctly measured values. This shows that the measurement quality is the decisive factor for the quality of the output values for a forecast.

If the calculated output values are then inserted into the equation of the “day ahead forecast” (equation 37.3), a mean absolute percentage error of 10.4% and a median absolute percentage error of 7.2% are determined in a period of one month under consideration by calculating the percentage error for each forecast value in this period with the aid of the actual measured value and then forming the mean value or median from this.

After the initial procedure for the calculation has been established, it can now be optimised.

In the first step, the performance values of the previous day are not used for the forecast, but the respective day of the week is compared. This means that for the forecast load of a Wednesday, the power values of the previous Wednesday are used. This ensures that the routines of the users are considered. On this basis, a mean absolute percentage error of 8.2 % and a median absolute percentage error of 6.2 % are determined. It can thus be seen that a consideration of the respective day of the week is target-oriented.

In the next step, this forecast is sharpened by further measured values. For this purpose, not only the performance of the exact time of day in the previous week is used, but also the performance of 15 minutes before and 15 minutes after the measured value used, as well as the measured values of the day a fortnight ago. To avoid deviations, not all values are used in equal parts, but empirically determined weighting factors are included. Figure 37.1 illustrates this procedure.

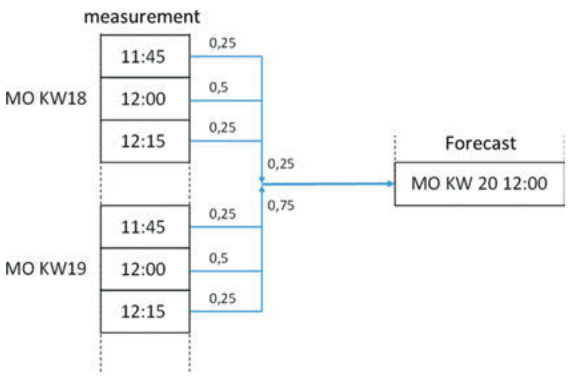

Figure 37.1: Principle of the extended weekday forecast.
(source: own illustration)

With this calculation, a mean absolute percentage error of 6.9 % and a median absolute percentage error of 5.3 % are achieved, which can already be considered very accurate.

It illustrates that it is helpful to add more measured values to the initial data set when determining the forecast values. From the measured values recorded for the quarter, it is shown that the user routine is relatively constant on the days from Monday to Thursday. The forecast for these days can therefore be sharpened by using the performance of the other working days to calculate the forecast value for a particular working day. Here too, as in the previous procedure, weighting factors are applied. The procedure is described in more detail in Figure 37.2.

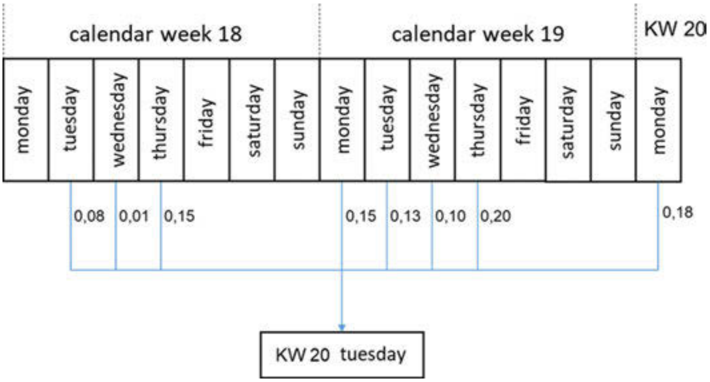

Figure 37.2: Principle of the working day forecast.
(source: own illustration)

The procedure can also be described by the following equation:

$$x_t = \sum (y_{t-96 \cdot i-1} \cdot 0{,}3 + y_{t-96 \cdot i} \cdot 0{,}4 + y_{t-96 \cdot i+1} \cdot 0{,}3) \cdot z_i \tag{37.4}$$

The factors z_i from equation 37.4 are again determined empirically by, among other things, recording and evaluating the error values mean absolute percentage error and median absolute percentage error when the parameters change over a period of several months. Figure 37.3 shows an example of a forecast of the quarter performance over two days.

With this forecasting method, error values of a mean absolute percentage error of 6.2 % and a median absolute percentage error of 4.8 % can be achieved in a period of one month. Moreover, this method is very precise in comparison. (Höft 2004)

37.5 Forecasting the Feed-in Power of Photovoltaic Systems

To be able to improve the energy management of storage systems, the expected energy converted by the photovoltaic system can be predicted using weather and system data, among other things. In this case, the predicted global radiation, the orientation of the system and the expected temperature are required.

For the photovoltaic forecast described in the following, measured data of the system output must also be available for several months, ideally over a whole year or several years. These measured values can come from a smart meter, for example, as quarter-hourly measured values. They initially form the data basis for the forecast and must be evaluated once with the influencing factors described above. The re-

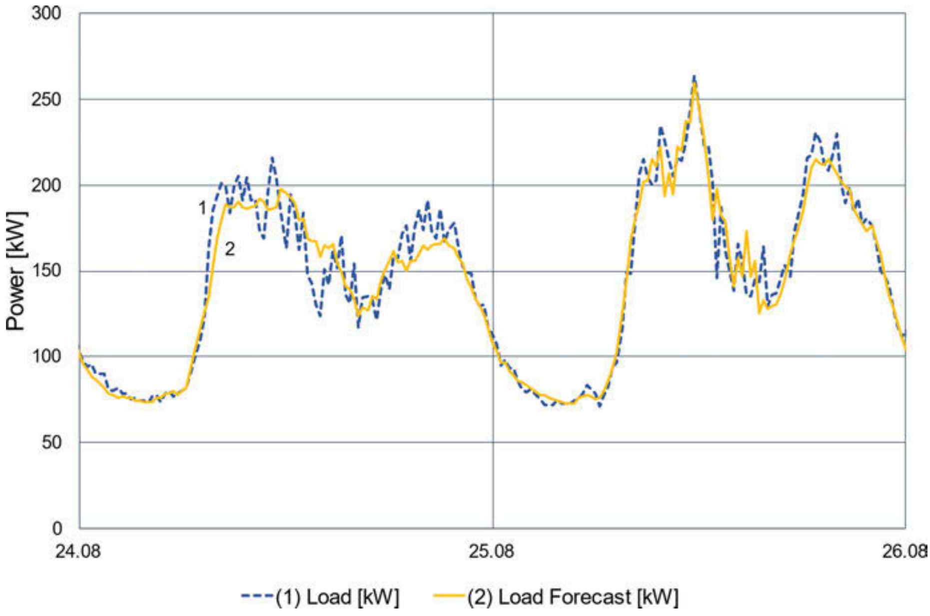

Figure 37.3: Electrical load forecasting in the low-voltage network.
(source: own illustration)

quired global radiation and temperature data can be retrieved from various online databases. To calculate the angle of incidence, the position of the sun is first calculated as a vector from the date, time, longitude and latitude. The required angle of incidence corresponds to the angle between the vector of the sun's position and the normal vector of the photovoltaic modules.

After the influencing factors are added to the data set, a system-specific database is obtained with which it is possible to make a forecast of the system performance by predicting a combination of the influencing factors (weather forecast for temperature and global radiation). To reduce the number of possible combinations of influencing factors, it is helpful to divide the numerical values of the influencing factors into ranges. Each range can then be given an index, resulting in an index combination that can be used to search for performance values in the system database. With the help of a Gaussian distribution, the expected value or a confidence interval (min. forecast/max. forecast) of the plant performance can be calculated for each combination. Such a forecast is illustrated in Figure 37.4 using two days as an example.

In this way, the required data set is very compact and can be integrated, for example as a table in the memory controller. As an extension, a radiation and temperature sensor would be possible, so that the data record of the plant is taught automatically or continuously expanded.

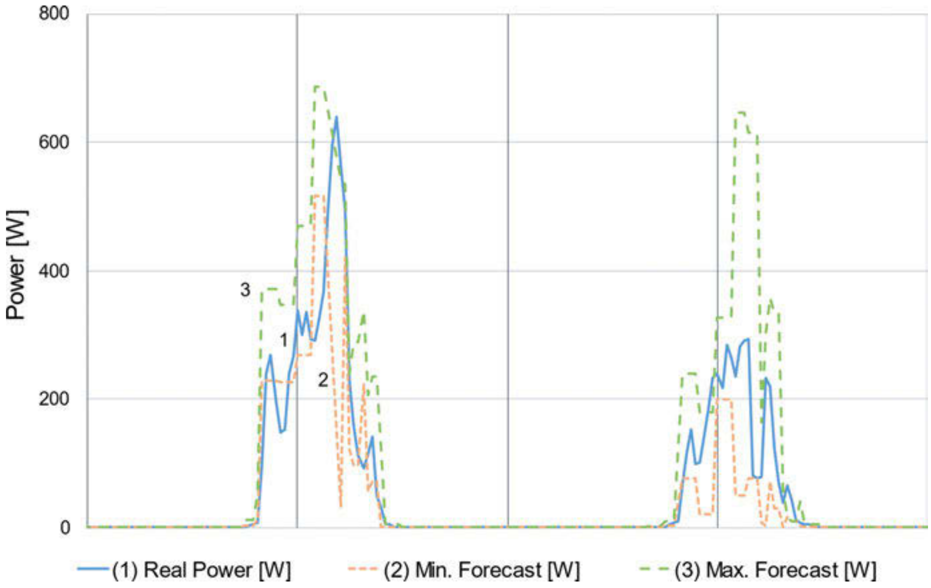

Figure 37.4: Forecasting the feed-in power of photovoltaic systems.
(source: own illustration)

37.6 Integration of Charging Stations and Heat Pumps

For load forecasting of charging stations, it is currently possible to rely on standard load profiles if no measurement is available. However, these are far too inaccurate to be able to control an energy storage system specifically based on them. For example, they assume a power value that is constant apart from a time range between 10:45 and 14:30. (Göbel 2022) However, the load profile of charging stations depends on many other influencing factors. These include the distance travelled by the electric car and the resulting energy demand to recharge the storage of the electric car, as well as when which vehicle is to be charged and with what power.

The same applies to heat pumps, whose load profile can only be roughly derived from the existing standard load profiles due to their complexity. The electrical load process of the heat pump depends, among other things, on the filling level of the thermal storage tank or the temperature prevailing in the building to be heated, as well as the type of heat pump used.

To be able to create a meaningful forecast, such as the previously described load forecasting for single-family and multi-family homes, it is necessary to directly measure the specific charging station or heat pump. This measurement data can then be included in the load forecasting.

The procedure can then be identical to the forecast for general consumers already presented. Only the factor z_i in equation 37.5 must be extended by the predicted values of the heat pump and electric mobility.

37.7 Storage Management

Based on the previously developed forecasting methods, the storage management can now be developed to prevent phenomena such as load jumps or load peaks, which can occur when the maximum State of Charge (SoC) of the storage is reached, and at the same time to ensure the highest possible self-consumption.

First of all, a simulative memory is assumed, in which charging and discharging curves as well as the efficiency of the memory are neglected. Furthermore, no error buffer is initially assumed for any deviations in the forecast data. In the next step, the most likely course of the reference power without storage intervention is calculated from the photovoltaic and load forecasting in order to be able to calculate the charging power of the storage for 15 minutes at a time. As soon as this reference power falls below the limit 0 W, this means that at this time the photovoltaic system is converting more energy than is being consumed at the same time. If no energy storage were used, this would mean that the excess power would be fed back into the upstream grid of the energy supplier. To increase the self-consumption of the photovoltaic system, this surplus power should be used to recharge the energy storage. If necessary, however, this excess power must be limited, as the maximum charging power of the storage unit must not be exceeded. The maximum power is determined as P_{max} of the energy storage device. From this possibly limited power, the maximum energy can be calculated which the storage could theoretically absorb in the predicted period. However, if this energy is greater than the remaining capacity of the storage unit to absorb energy, a reduction factor is calculated to ensure that the energy storage unit does not reach the maximum State of Charge (SoC) prematurely. This factor results from the ratio between the remaining available storage capacity and the sum of the total energy that can theoretically be stored during the charging process. With the help of the described reduction factor, the charging power of the storage unit can be calculated from the previously calculated maximum theoretical charging power.

With this charging management, it can be achieved that the storage tank is fully charged over the entire period in which the photovoltaic system converts more energy than is consumed, if sufficient energy is converted by the photovoltaic system on that day. This process is illustrated in Figure 37.5. This prevents additional load jumps that would occur if the storage system were fully charged early on and would then unnecessarily burden the grid.

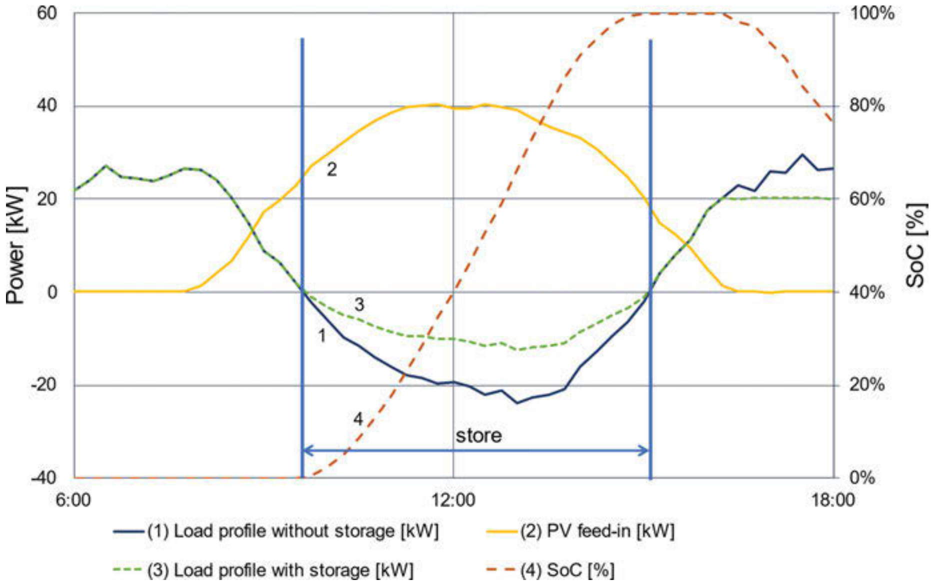

Figure 37.5: Forecast-based charging of the storage tank.
(source: own illustration)

For discharging, it is irrelevant from an energy point of view when this occurs, as long as the storage is fully discharged again at the beginning of the charging cycle in order to be able to resume the maximum energy. To minimise load peaks, it is advisable to use the stored energy when the energy demand is above average. The prerequisite for this is to know when load peaks will occur. By means of the load forecasting shown, it is possible to estimate the time when the load surges will occur and to adjust the state of charge of the storage unit beforehand. For this purpose, an average value of the consumption of the coming hours can be formed in order to detect whether the respective power is above average. Subsequently, the discharge procedure is very similar to the charging procedure, with the exception that the limit 0 W of the reference power is no longer decisive, but the average value of the consumption of the coming hours that has just been calculated.

The threshold for charging the storage is shown in Figure 37.6 by data series 3. With a sufficiently high State of Charge (SoC), the load process is limited to this threshold. The maximum discharge capacity of the storage unit must again be considered during the discharge process.

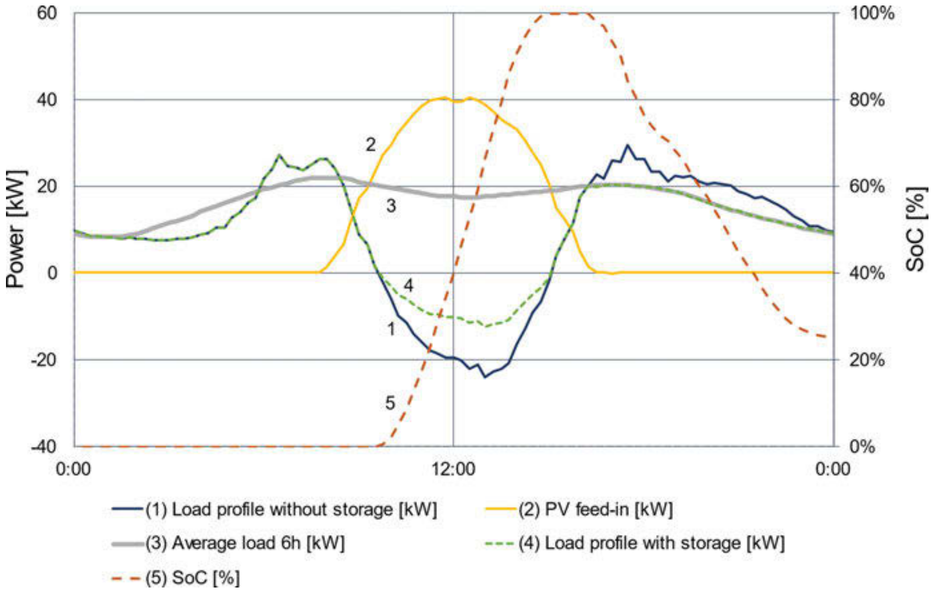

Figure 37.6: Forecast-based storage management with 6-hour average load.
(source: own illustration)

37.8 Final Consideration

The forecasting method presented in this chapter is a time- and resource-saving alternative to complex forecasting models using neural networks. As shown, a storage management system can be set up with the performance values obtained from this, with which it is possible that load jumps, which can occur with simple storage control, are prevented and load peaks are smoothed. This can be realised without significantly reducing self-consumption. This means that renewable energy from photovoltaic systems can be used more efficiently.

In the future, this forecast-based storage management can also be used for energy storage at neighbourhood level. As already described, the future integration of other types of consumers (such as heat pumps and electromobility) is possible, but not applicable in real terms without appropriate measurement of the respective loads. However, if these are also equipped with corresponding measurement systems, installed storage facilities can be used much more efficiently through forecasting.

Furthermore, with the help of the measurement data of one year, it is possible to simulate the storage management of different storage facilities with different parameters. This can be used to estimate the purchase of a real storage facility, to determine its parameters and to plan its profitability in advance.

Consequently, it can be prevented that a storage unit with excessive charging capacity or a too cost-intensive storage unit is used. This storage would only use its full potential on a few days a year.

In the context of the project "ZED (Zwickauer Energiewende Demonstrieren/ Demonstrating Zwickau's Energy Transition)", it is possible to achieve the degree of self-sufficiency defined in the project goals efficiently and in a resource-saving manner with the help of the developed forecasting method. Furthermore, this method may be used to develop a thermal forecast based on the heat loss recovery planned in the project, which is the basis for the coupling in the electric-thermal wide area synchronous grid. In this way, the designed thermal smart grid can be used even more efficiently.

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Erik Höhne, Michael Schneider, Carolin Alippi, Elisabeth Borbe, Oliver Scharf

38 User-Centred and Sustainable Local Mobility – A Participatory Approach in the Neighbourhood

Summary: With the neighbourhood concept developed in the ZED Lighthouse, the actors involved are not only trying to meet the growing demand for local mobility through a research mobility station with neighbourhood caretaker as well as age-appropriate e-scooters and autonomous boxes for e-scooters. Rather, this concept also opens up perspectives and offers all the necessary aids for older people to be able to live in their familiar neighbourhood – and thus also to keep the neighbourhood itself structurally stable. With the help of user-friendly and participatory technology development, those affected are involved in the creation of new (socio-)technical solutions. The blueprint from Zwickau-Marienthal creates new perspectives, especially for large housing estates with homogeneous age structures, to bind their residents to the neighbourhood in the long term and to keep the estates liveable and lively into old age.

38.1 Introduction and Project Background

Since 2017, the lighthouse project “Zwickauer Energiewende demonstrieren” (ZED, “Demonstrating the Zwickau Energy Transition”), funded by two German federal ministries, has not only been developing holistic solutions for concrete social and technical problems of the energy and mobility transition, but also testing them on a real scale at neighbourhood level: How can energy consumption be reduced in a neighbourhood, renewable energies be integrated into the energy supply in a socially acceptable way, and a smart coupling of electricity, heat and mobility succeed? In short: How can urban districts become climate-neutral – without ignoring social aspects? A prerequisite for (socio-technical) problem solutions that are both sustainable and accepted is the involvement of social actors in the research process: ideally, their expectations, experiences and know-how are brought together with scientific and technical knowledge in such a way that the results of the research process can be integrated into science and society (cf. e.g. Weyer/Schmidt/Kirchner 1995, Schneidewind/Singer-Brodowski 2015).

Erik Höhne, Stadt Zwickau
Michael Schneider, Ludwig-Maximilians-Universität München
Carolin Alippi, Alippi GmbH
Elisabeth Borbe, Johanniter Unfall Hilfe e.V.
Oliver Scharf, Westsächsische Hochschule Zwickau

https://doi.org/10.1515/9783110777567-038

To this end, ZED not only involves numerous actors from local politics and administration, companies, science and civil society in the research process from the very beginning, but also uses a wide range of different participation formats – from focus groups and discussion forums to test drives and measurement campaigns to a research mobility station. The jointly developed solutions are then tested and continuously adapted to the requirements of users and operators in a living lab, the urban district of Zwickau-Marienthal.

Zwickau-Marienthal, with its 8,000 residents, is characterised by Wilhelminian style architecture structures and small housing estates that were built around its former (village) centre in the 1920s to 1940s. In the 1950s and 60s, the large housing estates Marienthal-Ost and -West were built in the row construction style common at the time. According to the "Integrated Urban Development Concept Zwickau 2030" (Stadt Zwickau 2022), these large housing estates in particular are considered areas in need of consolidation. This means that, among other things, a reduction in the number of flats, "cautious" deconstruction, but also a (family-friendly) consolidation of smaller flats is necessary. (Stadt Zwickau 2022) This is necessary to promote the influx of young families, to introduce targeted measures for "the significantly increasing proportion of residents older than 65 years" and to counteract "higher housing vacancy rates". (Stadt Zwickau 2022)

In fact, Zwickau-Marienthal with its 7300 inhabitants is almost paradigmatic for the rapidly advancing ageing in eastern Germany: while the Federal Statistical Office (destatis 2021) notes a 5% higher proportion of people aged 65 and older in Eastern Germany than in the Western Germany for 2020 (26% vs. 21% of total population), the municipal administration of Zwickau reports a proportion of this age group of 29.4% for the entire urban area (Stadt Zwickau 2021). In Marienthal-East, the proportion of residents aged 65 and older is significantly higher again: it is 35.9% here, and in Marienthal-West, at 28.5%, the proportion is roughly in line with the Eastern German average. (Stadt Zwickau 2022)

In the Marienthal living lab, we are dealing with a predominantly older population, for whom the INSEK 2030 already names a number of important urban development projects: In addition to barrier-free design in development and renovation measures in the public sector, it also lists, for example, measures of action in senior citizens' facilities, in the traffic area or for the further identification of residents with their district.

This article focuses in particular on those activities of the ZED lighthouse that were carried out together with and for the older residents of the Marienthal living lab. The aim was to open up perspectives for senior citizens in particular and to offer them all the necessary building blocks they need to be able to live in the neighbourhood they are accustomed to – and thus also to keep the neighbourhood itself structurally stable.

The approach followed in ZED is based on the concept of participatory and user-oriented technology development, i.e. those affected are themselves made participants in the development of new (socio-)technical solutions. (Schneidewind 2014, Heite/Rüßler/Stiel 2015) This approach and its implications for older residents and their specific needs are presented in the next chapter (38.2). Its implementation as a concrete contribution to improving local mobility in the Marienthal living lab is then described in chapter 38.3. The article concludes with a summary and outlook (38.4).

38.2 User-Oriented Technology Development

In *Umwelten des Alterns* (English: the environments of ageing) described by Claßen/Oswald/Doh et al. (2014), the neighbourhood is of central importance for the quality of life of older people; because of the "distance sensitivity of old age", older people are not only "constant and critical users and connoisseurs of their neighbourhood" (ibid.), they also interact more strongly with their local environment than more mobile young people (cf. Heite/Rüßler/Stiel 2015). Not least because of their differently developed mobility resources, such as less possession of a driving licence, less availability of a car, and a reduced mobility rate and daily distance, older people are more firmly anchored in "their neighbourhood" than younger people. Innovations and changes in this regard must therefore be particularly well designed and justified, and in the best-case scenario, older people are involved in the development of innovative solutions as co-producers in order to be able to systematically use their everyday expertise, their wealth of experience and their knowledge (ibid.).

From the perspective of user-oriented technology development (Bijker/Hughes/Pinch 1987, Weyer 1997), the involvement of potential users in the R&D process gives them the opportunity to actively contribute their expectations and needs, but also their intuitions, heuristics and decision-making routines, and thus also improve the technical and economic chances of realisation (Gigerenzer 2013): A deeper understanding of the contexts of use as well as the everyday routines and expectations on the part of users enables, for example, more user-friendly product designs – and in general the development of technical systems and functionalities that people really want. This in turn should lead to fewer frictional losses in human-technology interaction (e.g. due to misuse) and to greater acceptance on the part of users (cf. Hickfang/Möller/Schneider et al. 2020).

A prerequisite for this, however, is consistently opening up of the innovation network of professional players for potential users and for their interests and strategies – which we believe is necessary because the requirements and needs can change in the course of innovation projects and because there is (still) no significant demand for many innovations at the time of their market launch. In addition, a new technology is often only tested in the laboratory or as a prototype, but not under practical conditions, so that potential users may shy away from the "risk of the new". For these reasons alone, the success of a new technology cannot be explained by supply and demand factors alone.

For the technology providers, such an opening up of the innovation network offers the opportunity not only to adapt their developments to the requirements of the potential users, but also to systematically include their idea potential and the context of use in the innovation process.

However, empirical studies, for example of "smart grid experiments" (Lösch/ Schneider 2017) or "urban labs" (Scholl/de Kraker/Hoeflehner et al. 2018, Reusswig/ Lass 2017), also show that innovation processes by no means follow a simple linear project course – from problem identification to idea generation to implementation in practice. Rather, they usually run in recursive loops, are characterised by numerous breaks and therefore resemble the "fireworks model of innovation". (Van de Ven/ Angle/Pooley et al. 1999) This means that they are subject to non-linear dynamics, surprises are pre-programmed, and the process is neither stable and predictable, nor dependent on chance. According to the authors, innovations are unpredictable not because they are at the mercy of chance, but because they are subject to a complex interplay of all actors involved in the process. The course of such interactions therefore represents an experiment with an open outcome, both for the participants themselves and for any observers.

Even if the courses of innovation processes and interactions regularly appear as (real) experiments, the authors observed three basic sub-processes of innovation courses, namely "initiation", "development" and "implementation", which are characterised by different events, actors, functions and framework conditions (ibid.).

Johannes Weyer (1997) argues similarly: he conceives of technology genesis as a "multi-stage process of the social construction of technology", whereby the actors involved in the process as well as their visions of use can change several times in the course of development. He describes the process itself as a sequence of social closures and subdivides it – ideally simplified – into the three phases of "emergence", "stabilisation" and "implementation": While in the "emergence phase" new, partly visionary and (initially) innovative technologies are usually developed away from established structures (typically in "niches" in the sense of Frank Geels' Multi-Level Perspective, Geels 2002), it is crucial for the "stabilisation phase" that social innovation networks of strategically capable actors are created, which not only take up the ideas, but also recombine their technical-apparative and social components and push forward the development of prototypes. In contrast, "enforcement" is an independent innovation process, which on the one hand must succeed in triggering recursive social learning processes that go beyond the "narrow" R&D networks from the stabilisation phase. On the other hand, the societal need for innovative technical solutions must first be "created" through "wide" networks with new actors from the user context. Without this change of actor constellations, without the opening of the innovation network and without the construction of societal demand structures and thus markets, even the most ingenious idea is doomed to failure.

This opening of the innovation network for the needs of potential users is described in the following chapter using the example of the development of innovative offers for local mobility, especially for older residents of the Zwickau-Marienthal living lab.

38.3 Participatory Development of Local Mobility Offers in the Marienthal Living Lab

The development and testing of own offers for older people in order to improve their local mobility took place in a multi-stage process, which can be described clearly with the three phases of the technology genesis model by Weyer (1997) already outlined above. Thus, the idea of creating such offers and developing corresponding technologies or services for them emerged outside of the established structures: not "classic" mobility providers or product developers, but niche actors from the user and user context raised awareness of the problem of only limited (local) mobility in the context of actor interviews and focus groups and proposed first neighbourhood solutions based on electric scooters for seniors (e-scooters). In the "stabilisation phase", the original ideas with their technical-apparative and social components were further developed within the framework of an iterative process with household surveys, test drives or creative workshops, new "strategically capable" actors were integrated into the innovation network and the development of a prototype – a research mobility station with its own "neighbourhood caretaker" – was advanced. In the "implementation" phase, adjustments were made to the requirements of the potential target groups, recursive social learning processes were initiated and thus the social need for these innovative socio-technical solutions was generated. In the following, the innovation process is outlined along these three phases of the technology genesis model:

Emergence Phase

The "generators of idea" were neither classic mobility actors, such as the local public transport provider, nor established product developers who developed this new mobility approach. Rather, the residents themselves reflected on the location qualities of their neighbourhood and provided creative input for a "future-oriented Marienthal". And it was the special project constellation with actors from the municipality, civil society, research and two service providers from the health sector – a nursing service and a medical supply store – that together set the further course of the innovation process.

At the beginning of the ZED Lighthouse, in-depth explorations were conducted with residents (N=10) and actors (N=16) of Marienthal with the aim not only to survey the image and other location characteristics of this neighbourhood from the respondents' point of view, but also to develop ideas and visions for a "future-oriented Marienthal". For many respondents, Marienthal is still a "place to feel good", a "very green", "great district" in a "good location", with a "great sense of belonging" and a high level of identification among the residents: "We are Marienthalers". Nevertheless, due to the "loss of jobs", but also of "shopping facilities", the neighbourhood has increasingly become a "purely residential neighbourhood", a "mere place to sleep". Due to the "slow ageing" and the "influx of people from other areas" and with "different views" ("you don't want people like that as neighbours"), "ever greater areas of conflict" had also arisen, the "sense of community and cohesion" had become much less. It is therefore particularly important to strengthen "the community" again ("everything that promotes relationships is to be supported"), to "make the neighbourhood more lively again", i.e. to "combine living and working", but also to secure "the supply of trade" and the "accessibility of shopping facilities", especially for older people. It is therefore necessary that "urban planning and development no longer abandon planning" and instead of "demolition and deconstruction" actively work on the "future of Marienthal", e.g. do something against "traffic noise", against "vacancies", but also for "affordable housing" and for a "life suitable for the elderly".

The respondents' expectations of the ZED Lighthouse were mainly directed towards the two topics "We are Marienthal" and "More environmental protection": While visions such as "e-mobility for all Marienthalers", "mobility on demand" or, in the building sector, "zero emissions with recognisable added value for the residents" were developed for the environmental topic, the first topic was about "strengthening the community", for example through participatory processes or the "development of committed networks" (instead of "all-round state provision").

In a second step, the interview results were presented in three focus groups – again with interested Marienthalers and actors – and concrete "technology projects" (Weyer 1997) for the two topics were developed together with ZED Lighthouse partners. In all focus groups it became apparent that "We are Marienthal" and "More environmental protection" can not only be combined, but also fit into the overall goal of ZED to demonstrate a climate-neutral neighbourhood with smart sector coupling without neglecting social aspects.

The core of the new socio-technical project favoured by all participants is based on the fact that "e-mobility for all" can shorten distances and increase activity radii, especially for older people, and in combination with a contact person ("neighbourhood caretaker") can also contribute to "strengthening the community". In detail:

Since the large housing estates in the living lab do not have demand-responsive access to public transport, nor are everyday activities such as shopping or visits to the doctor within easy walking distance for everyone, cars have been the main means of transport used for everyday action. Since the large housing estates in the living lab do not have demand-responsive access to public transport, nor are everyday activities such as shopping or doctor's visits within walking distance for everyone, the car was used as the main means of transport for many of these purposes.

From ZED's point of view, however, the use or even an increase of motorised individual transport is not sustainable due to the consumption of fossil energy and CO2 emissions. In contrast, the idea of establishing an alternative form of local mobility based on electric mobility is more sustainable, especially since it serves the interests of the residents (securing their mobility in the neighbourhood) and the project goals (decarbonisation and sector coupling). However, in order to ensure that all residents in the living lab have access to it, from the developer's point of view it seems appropriate to develop a kind of sharing system with intelligent networking. In addition to such a sharing system, it must also be ensured that all interested parties are instructed at the mobility hubs that are still to be set up, so that they can also use the system and e-vehicles properly. This is the task of the neighbourhood caretaker.

Also, as a result of the in-depth explorations on the neighbourhood condition at the beginning, a neighbourhood caretaker could be a useful implication of the project, whose function goes far beyond instructing the users. In this sense they do not only provide support in securing local mobility. Rather, they act as promoters of social provision – with the aim of creating an offer with low-threshold access, identifying needs and initiating chains of help for early intervention of problem situations. Neighbourhood caretaker, who are provided and paid by a project partner in ZED, form an interface in the residential area for the utilisation of supportive services. They act as a confidant for all residents in the neighbourhood, support the referral of professional help and help the residents to help themselves. By providing information and being regularly present in the neighbourhood, the "neighbourhood caretaker" actively shape the social space of the residential area with the involvement of the residents. This increases the residents' attachment to the neighbourhood and the chance of a long, self-determined life in their familiar social environment.

This socio-technical core based on age-appropriate electric scooters for senior citizens (e-scooters) and neighbourhood caretaker was opened up to other actors from the user context in the "stabilisation phase" up to "prototype development".

Stabilisation Phase

First of all, test drives (N=12) with subsequent interviews with senior citizens (cf. Figure 38.1) on their spontaneous impressions, their expectations and general (mobility) needs showed that despite some structural and road traffic-related difficulties, the e-scooter is an enormous relief and enrichment of everyday life, especially for the health-impaired drivers. And in combination with the neighbourhood caretaker system and smart sector coupling, it can also make a contribution to age-structured and energy-efficient neighbourhood development. Nevertheless, in the early stabilisation phase, there was still a lack of corresponding parking and charging options as well as booking, payment and support systems. In addition, there was a lack of valid information about the existing movement patterns of the neighbourhood residents, their mobility behaviour and their needs for alternatives and new mobility options.

For the implementation of possible options such as "e-scooters for all", further (market) analyses, concept developments and participation steps with new strategy-capable actors from the user and user context were therefore necessary. Thus, in the course of the project, corresponding concepts were developed in (creative) workshops

Figure 38.1: Test drives with senior citizens in the neighbourhood and subsequent survey. (source: ZED project (2019))

and public discussion forums such as the “ZED Forum”, but also discussions were held with potential sponsors, such as housing associations, operators of senior citizens’ homes, associations or voluntary services, as well as the (licensing) authorities.

At the second ZED forum “Marienthal – sustainably mobile”, more than 60 visitors discussed fundamental questions of the mobility turnaround and satisfaction with the local traffic situation (cf. Figure 38.2). At various moderated topic tables, people then considered what mobility in the neighbourhood could and should look like in the future in order to make it as attractive as possible for every citizen – whether young or old. In the opinion of the participants, options such as “e-scooters for everyone” should ideally be implemented in such a way that the station for renting vehicles is easily accessible (max. 500 metres from the home) and that there are also return points at exposed destinations (e.g. doctors, supermarkets, allotment gardens). It was also suggested in the ZED forum that the range of vehicles must also be usable for all age groups, so additional types of vehicles such as e-bikes and e-load bikes were introduced. Furthermore, the station itself should not only be a lending station, but also serve as a meeting point in the neighbourhood through an appealing green exterior design with seating options. Finally, the participants preferred a payment per use (no monthly flat rate). The costs should be based on those of public transport and at most be slightly higher. Flexible borrowing times without fixed opening hours would be desirable.

Central questions, such as the further development of the new mobility approach and the size of the potential market, were also integrated into the various waves of the ZED Lighthouse household surveys. The assessments made and new ideas formu-

Figure 38.2: Discussion forum on Mobility.
(source: ZED Project (2019))

lated there by the respondents (Number of cases > 1.300) were embedded in the further development process.

Overall, the results of the discussion forums, actor and household surveys showed that the idea of setting up a mobility station in the Marienthal neighbourhood met with a broad response, both from residents and potential users as well as from actors from the (local) business community and the city administration. The information gained in this way was iteratively integrated into the new mobility concept, which was created within the framework of the project by the coordination of the City of Zwickau together with the Innovation Network.

The aim of this concept is therefore to ensure (local) mobility for all residents of the neighbourhood and to offer target group-specific environmentally friendly vehicles (e-scooters, e-bikes, etc.). In addition, the designated station is not limited to a mobility offer: it is also intended to be a place for meeting and strengthening the community. The "neighbourhood caretaker" helps people to help themselves, enables participation and at the same time provides information about the ZED lighthouse.

The questions already raised in the ZED Forum about the location of the station, about a design that is as appealing as possible and fits in with Marienthal, and about the e-vehicles to actually be provided for different target groups were finally put to the vote in further participation formats (focus groups and surveys[1]). The decision

1 In total, there were three household surveys (two postal and one face-to-face survey – N: 740; 485; 103) and three focus groups (topics: old and young/ economic actors / social services and neighbourhood caretakers – N: 15 each).

was again based on the open and transparent project approach and was made in favour of a flexible, open and modern container solution Containers offer the advantage of being barrier-free, and they can – if necessary – be moved to other locations almost at will. It was also decided to equip the e-scooters with GPS tracking modules in order to learn about particularly frequently travelled routes and the destinations of the users. This could, for example, lead to the creation of further service or rental stations at highly frequented locations, or conversely, conclusions could be drawn about the structural or traffic condition of routes and paths that are hardly used, and measures for change could be suggested. This makes it clear that the development of the mobility offer is never complete with the completion of a station, but that the user, whether directly or indirectly, will always have a say in the further development with his or her information and tips.

A first important step towards stabilising the offer was taken with the opening of a prototype in summer 2020 (cf. Figure 38.3). In order to promote the visibility of this station, a communication concept was developed in advance by the project partners. Both the opening ceremony itself, to which all neighbourhood residents received invitations, and the subsequent campaign week with topics related to the new mobility service were well attended and received a lot of attention from local media. The mere fact that a mobility station is something new for Zwickau encouraged a positive response. In particular, its permanent presence (the station is open from 8 a.m. to 6 p.m. during the week) and the permanent presence of ZED project staff and neighbourhood caretaker created curiosity and led to countless conversations, especially with those residents who were not interested in borrowing an e-scooter. In a short time, the residents of the neighbourhood adopted the station as a new meeting place and space for conversations – among themselves and/or with project staff.

Through these discussions with the residents and the first users, as well as through accompanying systematic surveys, numerous insights were gained in the first weeks to further improve the service. As a result of the feedback, for example, the opening and break times were adapted to the demand and the rental offer was expanded to include a transport option with e-cargo bikes. In particular, the data collected on borrowing purposes, frequency and duration of use, as well as the willingness to pay for the service, which was initially still free of charge, should optimise the operation in the long term. However, this data and the results from the surveys are not only aimed at improving the mobility offer, they are also intended to make a contribution to sustainable neighbourhood development. The focus is on the following topics:

- What are the barriers to use among users? What are the preconditions for (improved) acceptance of the services by the users? How the offer could be further developed?
- What other types of vehicles would come into question and thereby expand the range?
- Can additional added value (neighbourhood pilot, information opportunities) strengthen the basic function of a lending station for sustainable, alternative mo-

Figure 38.3: The research mobility station opened in summer 2020.
(source: ZED project (2020))

bility in the neighbourhood and thus push the transport transition as a component of the energy transition?
- Beyond its function as a meeting place, how can the research mobility station also contribute to "strengthening the community"?
- Which professional services are necessary/desired to enable a long and self-determined life in the home environment?

In the course of the first months of trial operation, it became apparent that the strict limitation of lending and return times could prevent some borrowing opportunities: For example, some doctor's appointments could not be kept or summer evening activities, such as allotment garden visits, were not possible as a result. However, extending opening hours is a challenge, as staff costs in particular are a major cost factor for running such a station.

Against this background, the project consortium developed the idea of creating an autonomous, digital lending facility. A "mobility box" ("Mobilbox") to be operated by the users themselves (cf. Figure 38.4) makes it possible to borrow a scooter around the clock. After a one-time registration, they can independently borrow and return their e-scooter with a user card. At the same time, the operators record the user and the borrowing times via a digital interface.

The design of this box was also done in an iterative process with the participation of the users. This made it possible to organise the entire lending process in a target

Figure 38.4: Autonomous "Mobilbox" and e-cargo bicycles as further development of the mobility concept.
(source: ZED project (2022))

group-specific and user-friendly manner as simply as possible. The feedback from the users also led to further improvements of the "Mobilbox" itself: Not only illustrative instructions for use and audio-visual accompaniment were developed, but an automatic light for borrowing in the dark and a traffic light solution that indicates the availability of vehicles have now also been implemented in the system. This feedback of findings and experiences from the user context were also enormously helpful for the hardware and software developers of the participating university.

Implementation Phase

Lighthouse projects like ZED have the chance to develop new ideas and also test them extensively in the living lab. Economic viability plays only a subordinate role, which hardly needs to be considered during the R&D process. But for the operators, the financing of the now "finished" technology is fundamental for a continuation after project completion, and for a permanent implementation of the mobility concept in Marienthal – but possibly also elsewhere – the existence of a market is decisive. On the part of the actors, there are various options and considerations that can play a role in financing the offer and creating markets:

- Refinancing through different tariffs for users
- Cross-financing of the mobility offer by sponsors of the neighbourhood (housing industry as well as entrepreneurs and service providers who profit directly or indirectly through an increase in customers)
- Cross-financing as a component of a neighbourhood service that can be booked via smart-home tools of the surrounding flats
- Financing of a staff-operated mobility station by integrating different uses (neighbourhood pilot, parcel station, sales opportunities for products, etc.)
- Economies of scale of “mobility boxes” and associated cross-financing of staff-operated mobility stations

The integration of further locations and the associated expansion of the network of actors is also crucial for the long-term success of the concept. Only if mobility is permanently available for the users and their mobility purposes (shopping, errands, stops) and is close enough to their homes, a mobility offer is a concrete option for use.

In perspective, it is therefore a consideration for those involved in the project, but also for later operators, to create a network of mobility points where the rental of e-scooters is possible. The already existing research mobility station could be the “spider in the web”, so to speak, where expertise, instruction and registration are bundled and backed up by permanent staff. The many mobility points are then populated by the “mobility boxes”, so that through their economies of scale, mobility stations also become profitable. As this approach is also a possibility for other districts with similar needs, initial impulses have already been integrated into urban mobility concepts based on the experiences of the Marienthal research mobility station and box. This adoption of the project results into urban planning guidelines and concepts is also a major goal of the ZED Lighthouse.

38.4 Summary and Outlook

Far-reaching demographic changes and the individualisation of lifestyles are making the population more diverse – even into old age. Cities and neighbourhoods are facing growing challenges in this regard, as age-related changes in demand and supply are also taking place: for example, demographically induced housing vacancies can destabilise neighbourhoods. As a result, new forms of social infrastructure provision are needed to make society and municipalities more robust and age-appropriate.

With the neighbourhood concept developed in the ZED Lighthouse, the actors involved are not only trying to meet the growing demand for local mobility through a research mobility station with age-appropriate e-scooters and autonomous mobile boxes. The concept is also intended to offer all the necessary building blocks and open up perspectives that older people need in order to be able to live in their familiar neighbourhood – and thus also to keep the neighbourhood itself structurally stable.

The residents are involved in the development of new (socio-)technical solutions within the framework of user-friendly and participatory technology development. For the acceptance and thus the success of the mobility product, a solution that is as custom-fit and low-threshold as possible is necessary, especially for the older target groups – a solution in which the necessary digital elements are integrated in a user-friendly way and which also meets the requirements of the market and sustainability. Such a research and development process uses the experience and creative potential of the users as well as the expertise of the developers to continuously optimise the product so that its handling in operation is as simple and safe as possible. In practice, the technology genesis model has proven fruitful: The need has been identified, and the offer was continuously adapted to it in recursive loops. The changing constellation of actors from science and practice proved to be conducive to this.

Nevertheless, it must also be critically noted that innovations can also fail. That is why it is crucial to transfer the results into a sustainable business model. The fact that payment for the services has not yet been possible due to funding modalities, combined with the comparatively high fixed costs of the mobility station and boxes compared to app-based sharing services of established offers, leads to unanswered questions regarding refinancing outside of the project context. User-friendly and participative technology developments, as practised in the ZED project with the mobility station and the autonomous mobility boxes, are not straightforward. On the one hand, the offer must be designed to be as useful, convincing and simple as possible for users, which has been achieved through elaborate, iterative adjustment loops of the approach. On the other hand, innovations in the neighbourhood require great efforts to promote the offer, especially at the beginning. The target group-specific approach as well as free use show the effort and the low hurdles. All in all, this can often only be covered by funding projects.

However, the blueprint from Zwickau-Marienthal creates new perspectives, especially for large housing estates with homogeneous age structures, to bind their residents to the neighbourhood in the long term and to keep the estates liveable and lively into old age. In cooperation with the housing associations, especially smaller decentralised solutions in front of the entrance areas of flat blocks, such as the mobile boxes developed in Zwickau, offer enormous potential, on the one hand to provide mobility even closer and more targeted to the residents, on the other hand it also opens up new sales opportunities for the operators themselves due to economies of scale, as mobility is now possible for everyone from and to the doorstep. Enquiries from other cities demonstrate the need of municipalities to create age-appropriate services in neighbourhoods, so that the actors involved are confident that this solution can remain established after the project period.

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https://doi.org/10.1515/9783110777567-039