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Energetic communities: Planning support for sustainable energy transition in small- and medium-sized communities

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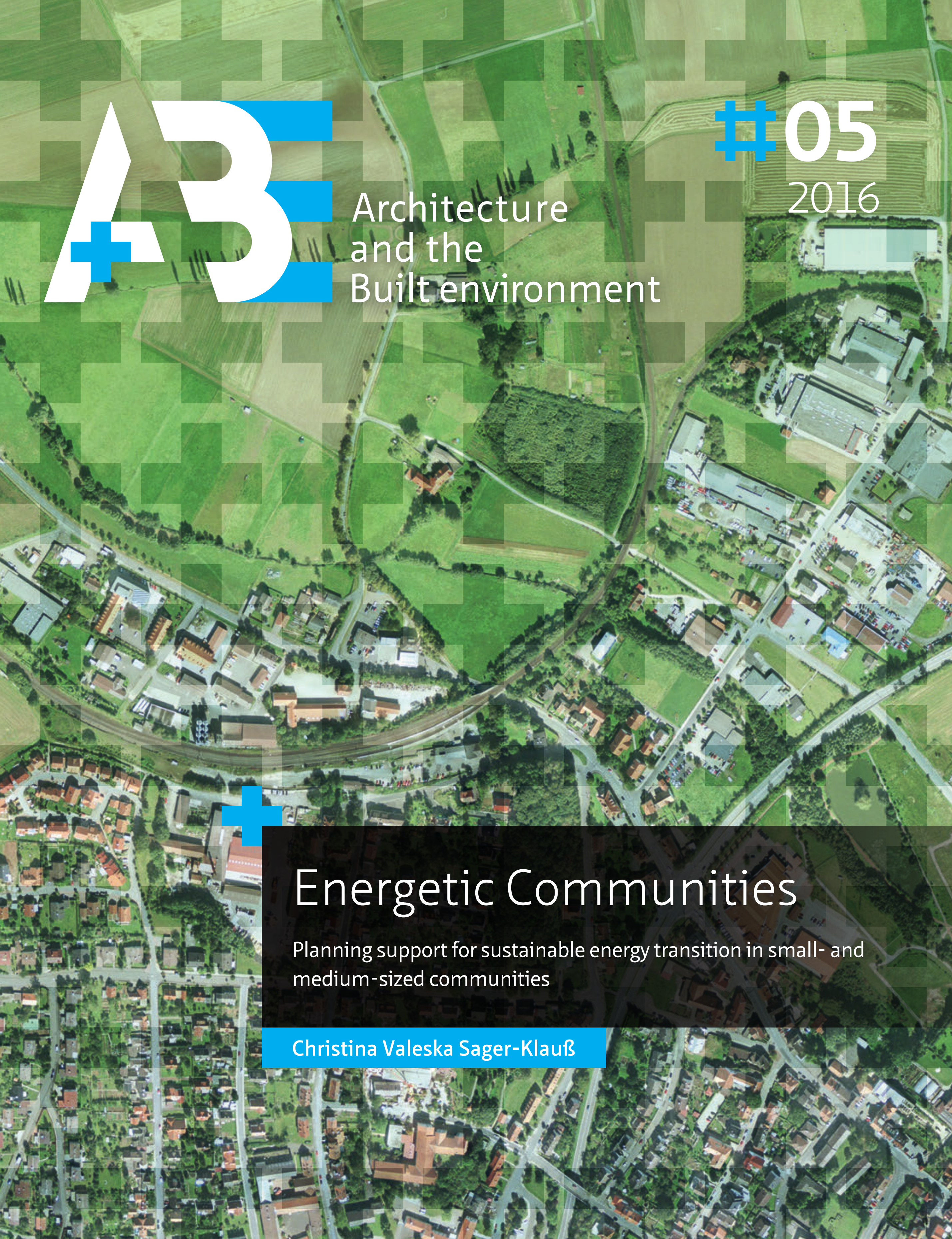

Architecture and the Built environment

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2016

Energetic Communities

Planning support for sustainable energy transition in small- and medium-sized communities

Christina Valeska Sager-Klauß

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Energetic Communities

Planning support for sustainable energy transition in small- and medium-sized communities

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door
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1 Introduction: Energy and Communities

"If we use resources productively and take to heart the lessons learned from coping with the energy crisis, we face a future confronted only, as Pogo, once said, by insurmountable opportunities. The many crises facing us should be seen, then, not as threats, but as chances to remake the future so it serves all beings."
L. Hunter Lovins

§ 1.1 Background

This dissertation was developed in a context where the urgency for energy transition was out of dispute. Young researchers of my generation have grown up with the warnings of the Club of Rome (Meadows *et al.* 2004), a follow-up of their well-known 1972 report, the Brundtland report (Brundtland *et al.* 1987), the sequence of UN World Climate Summits and the increasingly desperate attempt of the Nations worldwide to agree on mandatory targets. Energy-efficient building design and the use of renewable energies with active and passive strategies naturally belonged to the curriculum of the less traditional architectural and urban planning faculties. German influential institutes as the Institut Wohnen und Umwelt (IWU) in Darmstadt and the Institut für Energie- und Umweltforschung (ifeu) in Heidelberg both founded in the 1970's were established authorities in sustainability research und influenced us with many substantial publications and studies. But also the German Wuppertal Institut Klima-Umwelt-Energie (WI) and the Deutsche Bundestiftung Umwelt (DBU) were already founded and well established when I commenced my university career in the 1990's. The publications and projects of these German institutes opened the scope towards international research groups and institutes working in the field. Mainly during my professional career at the Fraunhofer Institute for Building Physics and mainly through several projects in the framework of the IEA ECBCS Annexes, contacts to colleagues all over the world from the US, Canada, Japan, Sweden, Denmark and The Netherlands researching in the field of sustainable energy development, influenced my interest in the topic.

But even though the atmosphere of following ecological principles in planning accompanied me from the university on, the tenor and content of the discussion on sustainability and renewable energies has significantly shifted since then. Probably the full complexity of the problem to be solved only unravels with growing insight and experience, and so today the other side of the coin of energy transition seems to dominate the media. Rising electricity prices caused by the very successful incentive programme for renewable energies cause the feeling of an uneven distribution of costs and benefits. Devastating news about inflammable insulation materials and toxic emissions from energy-saving light bulbs has led to a growing uncertainty regarding efficiency measures.

After a period of fierce determination to turn the wheel against climate change, it seems that there is a growing resignation among politicians, planners and the public because some things have not turned out the way we'd expected and the hope for quick solutions fades. Rebound-effects seem to eat up the savings to a good extent, and alternative ideas of how sustainable growth may function or how our economy may work without growth have not yet been persuasive (cf. Madlener & Alcott 2011). Energy systems have proved to be complex. They still rank high on political agendas, but in practice there is a growing uneasiness about the right steps to take. There is still a principal agreement to energy transition (cf. Borgstedt *et al.* 2010). The Fukushima disaster has strengthened the political will for transition in many countries although in Europe the pressing problems of the financial crises of the years 2008-2015 made the energy discussion seem less urgent.

The growing experience with energy projects on a national, communal and local level has sharpened the view for conflicts and things that can go wrong. On the other hand there are plentiful examples of success, innovative technologies and working implementation strategies. There are courageous initiatives from public and private corporations that are willing to bear the risks of transition and are inspired of rather doing something at all than surrender in the face of the complexity of the task; many of them in small- and medium-sized communities. Planners are used to deal with complex issues, technicians perceive problems as challenges. The combination of proven technical solutions and political will, good planning and strong backing in civil society are the preconditions to achieve progress in energy transition towards a sustainable energy system.

With this dissertation I hope to make a contribution to a better understanding of the complex correlations in communal energy systems and an improved communication between the different professional disciplines.

§ 1.1.1 The megacities aside

Certainly, there is a strong focus today on the problems that evolve with the growing megacities around the world. Undoubtedly great challenges arise with the ceaseless stream of people to the world's economic centres, hoping for better living conditions and jobs. Housing, transportation and continuous supply of food, water and electricity appear overwhelming challenges for the booming cities worldwide. The cities we see in our mind's eye look like Dhaka, Delhi, Manila or Mexico City. Huge city dimensions coupled with a clash of incredible wealth and disastrous poverty. The need for action, new technology and innovation is apparent from what we see on television and read in the news. The problems of endless immigration, slums, homelessness, health-threatening air pollution and ever-growing landfills startle and concern us. These cities need a sustainability revolution, I think, for the sake of their development, their population and the global climate. Sustainable development and interchangeably energy transition seems to be a topic at the large-scale. In the ranking of the largest cities worldwide, the first European entries are London and Paris (more than 10 million inhabitants) at the ranks 26 and 27. The largest German city Berlin, with 3.5 million inhabitants, and the largest city in The Netherlands, the metropolitan area of Amsterdam, with a little over 1 million inhabitants, seem to play in a totally different league. The assumption that also the specific problems and possible solutions differ significantly from megacities with more than 25 million inhabitants like Tokyo, Guangzhou, Jakarta or Seoul is evident.

At the same time politicians and scientists stress the responsibility of the developed world, namely Europe and the USA, to take action in fighting the threats of climate change and a sustainable and renewable energy supply and the Rio Declaration of 1992 specifically addresses the role of cities and communities in this quest. If we follow the headlines about city development in the past years, there seems to be a revival of urbanism. Cities still grow, or grow again. People, especially young professionals and older people, return to the city for living. It seems like the trend of the dissolution of the old city caused by urban sprawl has reversed, as was described by Sieverts (2001). Is there really a mentality shift from 'off-to-the-country with single-family house and garden' towards a growing attraction of dense urban living? Can we solve our energy problems in an urban context and more or less omit the rural back country because of diminishing relevance? Is energy transition a 'city topic' because of the high density of demand and the limited spaces to harvest for instance renewable energies?

In this thesis work I follow the hypothesis that a large share of the total energy transition has to be solved in small- and medium-sized communities. That is because in central Europe we have a different tradition in urban development and because of the developed infrastructure a far greater level of decentralisation than in many countries of the developing world. This leads to the situation that in the perspective over the coming century we will not have a comparable development of high-density agglomerations exceeding the ones we already have. Western-European countries are already densely populated, but there is greater diversity in the growing regions than in other parts of the world. I believe that the development of strategies and approaches for energy transition are relevant for small- and medium-sized communities because of their sheer number and the great potentials that lie therein. This makes this topic relevant for large-scale political strategies as well. It is also assumed that the preconditions for growth or decline, the successful development or the downturn of European cities is not determined by their population size. Contrary to metropolitan regions in other parts of the world, the economic and cultural centres in Europe are less centralised. Therefore I see great opportunities for the future development of small- and medium-sized communities in the context of renewable energies, new ICT solutions and new working models.

This thesis' work is therefore dedicated to approaches of energy transition in communities and small cities or towns, because we believe that the idea of sustainable urbanism shows far below the sizes of megacities in our direct neighbourhoods.

§ 1.1.2 The relevance of small- and medium-sized communities

Europe has a long tradition of town foundations. Contrary to the agricultural areas around the towns the economic and social life was always characterised by specific rules and greater freedom for entrepreneurship. European cities are decentralised central places that offer services and cultural life for their vicinity. Due to the long history of city developments there is a fairly even distribution of medium-sized towns and cities all over Europe. Mostly founded as market-places, the distances and locations were determined by non-motorised transportation and logistics. In 1933 the German geographer Walter Christaller developed a model for the geographic distribution of cities and towns of certain sizes and with certain functions. His work is commonly known as 'central places theory'. The central idea is economic: each central place serves the surrounding hinterland with goods and services. The higher level goods and services are centralised and serve more subordinate units. Through competition for space a more or less regular hexagonal pattern of higher to lower order centres develop. From the analysis of central places in Southern Germany he concluded the geometric progression of the hierarchical and spatial arrangement of central places (Christaller 1980, c1968).

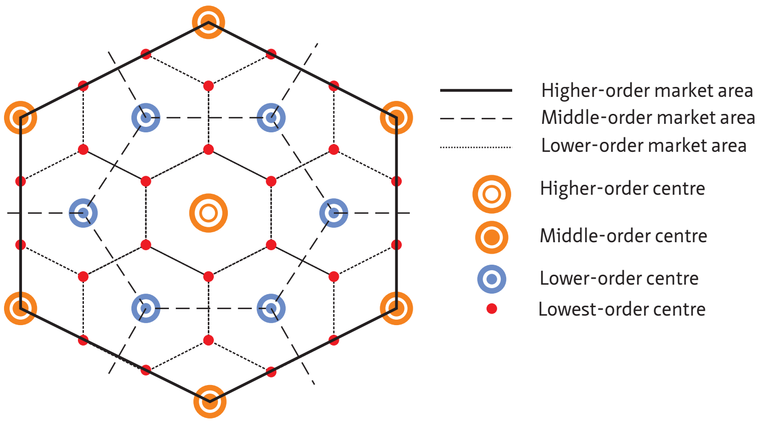

FIGURE 1.1 Hierarchical and spatial arrangement of central places (after Pacione 2009)

The work of Christaller found broad recognition, especially after an extended approach of August Lösch (1940) in Germany and the Scandinavian and Anglo-American regions and has been a popular basis for the analysis and development of towns and settlements. Despite the restrictions in the practical application of the theory the decentralised approach has been dominant in regional planning in Europe after the Second World War. The differentiation of higher, middle, lower and small centres with their specific services and infrastructure has been a leading principle for superordinate regional planning. In combination with the long tradition of city development in Europe this leads to the large number of moderately sized towns with high political autonomy and service functions we have today. The middle-order centres commonly have the planning authority over several lower-order centres within the community boundaries. The middle-order centres are not defined by size or inhabitants but by function.

In this work I am focussing on cities below approximately 100,000 inhabitants of size. Above 100,000 inhabitants I regard the city to be a large-scale city with different structural conditions. This classification is of course arbitrary since there are other important factors for the applicability of the transition approaches than inhabitants. On the other hand it gives the reader an idea about the type of town this study is focussing on: the type of town one only knows by name, if one has a personal connection to it. These towns and communities barely have an urban appearance; mostly they have local significance as central place for secondary schools, administration and retail. Certainly, the central places theory by Christaller has undergone transition in practice. Increasing mobility, the increasing scales of common retail units and administrative centralisation have led to shifts of the typical service functions towards the higher-ranking categories. Therefore maintaining functions is a current interest of many of these communities.

In Europe there are roughly 450 cities larger than 100,000 inhabitants. Approximately 40 % of the Europeans live in these urban regions (Eurostat 2012). The majority of inhabitants live in cities smaller than 100,000. This is also the case for Germany, were even 69 % of all inhabitants live in the smaller communities and towns. This is mainly due to the decentralised political and administrative tradition in Germany. Table 1.1 gives an overview over the city and town classes in Germany.

CATEGORY	Typical Size (in 1,000 inhabitants)	Number of inhabitants total (in million)	Number of cities / communities	Average number of inhabitants / km²
Small community	0 – 2	21.4	7,012	~ 200
Small town	2 – 20	14.6	4,628	~ 500
Middle sized town	20 – 100	21.6	619	~ 1,000
City (small)	100 – 500	12.2	68	~ 1,500
City (large)	> 500	13.1	14	~ 2,500

TABLE 1.1 City sizes and inhabitants in Germany (from Bullinger et al. 2011)

Since the European city statistics do not cover all towns below 100,000 no absolute number of smaller communities can be given here. The European statistics use a regular spatial grid and identifies urban and rural areas by the number of inhabitants per km² (Eurostat 2012). Since this work is focussing on the political decision-makers and urban planners, the focus is rather on the communities with planning authority. European countries as Germany and The Netherlands have a decentralised urban planning structure, where communal planning has high autonomy in the range of the superordinate frameworks.

From the facts mentioned, it can be assumed that the focus of this PhD work on small- and medium-sized communities has high relevance for application in practice. In this dissertation the term 'communities' is interchangeably for the legal entity of municipalities as spatially definied authorities. I am aware that the size of a community by inhabitants is only but a rough first classification. More important in this context are the ability to take political decisions and the planning authority to implement energy transition projects. The transferability of results is a leading aim for the research and analysis. Wherever it is possible, correlations and comparisons to other communities next to the case study will be drawn.

§ 1.1.3 Urban planning, sustainability and energy

Urban planning and urban policy are dealing with the processes of urban change. These are dynamic and continuous processes. The perspective is commonly long-term; communities develop over decades, centuries. The legal structure for structural planning in The Netherlands and in Germany is comparable. In both countries the communities have a high autonomy in their local planning decisions and development strategies. Figure 1.2 and Figure 1.3 show the structure and contents of spatial planning at the different scale levels. It can be stated that the national influence in the Netherlands on regional and local planning is greater than in Germany. Here the control functions bundle at the level of the federal states' administrations. The communities as local planning authorities nevertheless have similar functions and competences. The results from the different case studies in both countries should therefore show a good comparability in principle.

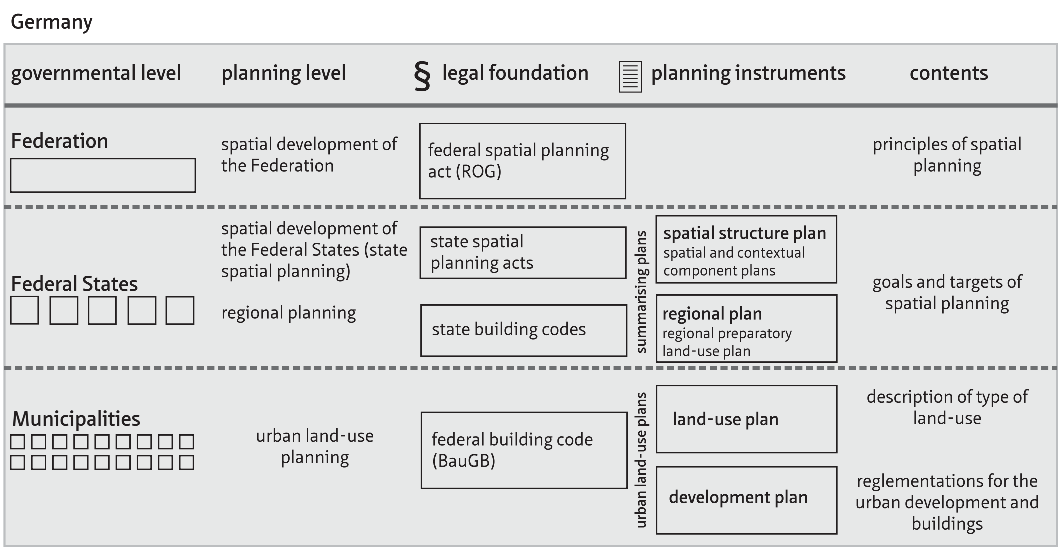

FIGURE 1.2 Spatial planning structure in Germany (from Kragt *et al.* 2003)

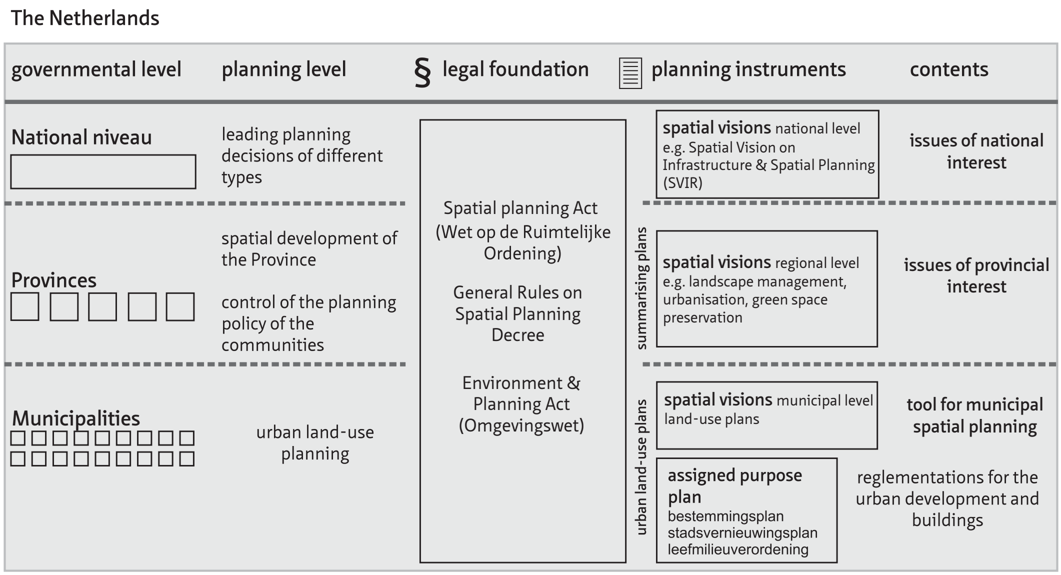

FIGURE 1.3 Spatial planning structure in The Netherlands (cf. ibid. and www.government.nl.)

In urban planning processes the correlations between the different actors are rarely simple and sometimes the outcome of decision making is unforeseeable. The basic principle of planning is based on the weighing of different and conflicting interests. The quest for optimisation of single aspects is not a core planning principle. The core idea of communal urban planning is to take creative influence on the shaping of the 'urbs' (Latin for city) which includes more than the layout of the built environment but encompasses also social and economic aspects. Urban planners traditionally regard themselves advocates for the residential groups not represented by market and economy (cf. Sieverts 2001). Therefore the scientific approach of mathematical optimisation is often not applicable in planning, simply because the necessary boundary conditions cannot be defined precisely enough. This is one significant difference that substantially divides urban planning end energy planning. The planning of energy grids, power plants and supply lines is very much concerned with optimisation processes. It is usually focussed on shorter terms and economic considerations. This is why at a first glance urban planning and energy experts often don't speak the same language when they talk about the same project from their points of view.

Today urban planning is often focussed on sustainable development, which logically includes the planning and consideration of sustainable energy systems as a sub-topic of sustainable development. Some European governments have anchored the priority of Climate Protection and sustainable development in their planning directives, for instance in the National Planning Framework in the UK: "The purpose of planning is to help achieve sustainable development." (Department for Communities and Local Government 2012). The aim to facilitate the process and to achieve a broad participation and action on a communal level is regarded an important precondition: "This National Planning Policy Framework changes that. By replacing over a thousand pages of national policy with around fifty, written simply and clearly, we are allowing people and communities back into planning" (ibid.). In Germany the sustainability targets are anchored in the National Building Code: "Land-use plans shall safeguard sustainable urban development and a socially equitable utilisation of land for the general good of the community, and shall contribute to securing a more humane environment and to protecting and developing the basic conditions for natural life" (Bundesministerium für Verkehr 2004, § 1 Abs. 5).

In practice the realisation of sustainable development in urban planning in combination with innovative energy systems is still difficult. All disciplines have to learn about the modes of work in the other fields and come to integrative approaches. Energy planning in the past was often delegated by the communal governments to either communal utilities or superregional energy service companies (ESCOs) and then was limited to the planning of technical infrastructure such as power grids and power stations. To some extent this was triggered by European Directives for the liberation of energy markets but it was often seen as an easy step to externalise the monetary risks of unpredictable developments under precarious financial situations in the communal households. Today there is the beginning of a reverse trend of an increasing recommunalisation and residential energy supply cooperatives. The great advantage of small- and medium-sized communities lies in the manageability scale, the options for direct participation and individual optimisation potentials. This dissertation shall contribute to a better understanding of energy systems correlations, open the view for new perspectives and synergies in the crossover of planning and technology disciplines.

§ 1.2 Problem statement and objectives

The necessity for transition in the energy sector is beyond dispute and high on the political agendas. The problems of a sustainable development in the energy sector are discussed on different scale levels and by numerous parties from different disciplines. In practice this leads to approaches that reflect the different disciplines' methods and priorities. In the worst case this leads to interest conflicts and stand-still. Urban planning, energy technology and environmental and social sciences sometimes follow different targets.

§ 1.2.1 Problem statement

Looking at the present situation in the realisation of energy projects on a community level, it can be stated that, in the majority of cases, the projects realised are not integrated in a holistic development strategy. Small- and medium-sized communities often don't follow their own energy development plan but commonly outsource energy supply to external investors and regional or over-regional ESCOs. Nevertheless energy transition takes place on a local level. Long-term transition processes are well located at the level of urban planning, because by tradition urban planning is focussed on the long-term development and not on short-term profit. Energy issues are a fairly new topic in strategic urban planning and development. The dissertation's scope is therefore also on information and technological issues and how to translate them into planning processes. The amendment of the German Regional Planning Act and the German Federal Building Code of 1997 emphasize the integrating function of regional planning and general development planning for sustainable development (§ 1,2 ROG, § 1 (5) BauGB). Communities are obliged to take action in the transition process towards a sustainable development. It is therefore important for communal decision-makers and administrations to build competences in the field of local energy supply and demand structures to enable strategic decision making in a long-term perspective. This competence building process is today not a common task in small- and medium-sized communities. Within the complex and broad field of energy systems, renewable energies, energy consumption and regulations it is a discouraging task to create an overview about the relevant aspects and to create a long-term development strategy. Communities' progress often depends on the competences and interests of individuals. The available planning tools are not addressing the needs of planners and decision-makers in small- and medium-sized communities in that respect.

In order to monitor the energy transition process in communities indicators are needed. By the judgement of the German Council of Experts for Environment Issues the existing indicator sets have deficits in the missing correlation to political environmental targets (SRU 2008). A systematic connection between targets, strategies and indicators has been on the agendas for quite some time but remains the exception in practice (Kreibich 1999). The implementation of energy transition into practice demands for a reduction in modelling complexity. At the same time a certain complexity has to be maintained to reflect the correlations between the different sectors (Thierstein & Lambrecht 1998). To put the problem of energy transition in small- and medium-sized communities to the point it can be stated that highly motivated initiatives fail in long-term success because they lack personal know-how, strategies and applicable tools.

§ 1.2.2 Objectives

This dissertation contributes to the discussion of energy transition processes in cities and communities. The dissertation aims at bridging some of the conflicts described in the problem statement by focussing on synergy potentials between different aspects of energy transition. The work shall support decision-makers and planners at the communities, who often find themselves in the very centre of the conflicts.

The central objective of this thesis is to provide stakeholders and decision-makers in small- and medium-sized communities with an approach for energy transition to create a more self-sufficient and resilient energy-system based on renewable energies. The outcomes shall support the implementation of energy transition strategies on a local level and enable planners to overview the consequences of measures in the context of the entire communal energy system. This requires a better understanding of the complex interactions within energy systems. The thesis takes the planners' perspective, which is regarded the central perspective also from the strategic perspective of political decision-makers, to address energy transition and task-based strategies (Werheit 2002).

This dissertation aims at supporting transition projects in small- and medium-sized communities. To achieve this, sub-objectives shall contribute to the central objective as milestones. The sub-objectives, which correlate to the global objective of the work, can be structured in four principal topics.

- Sub-objective 1: Support the definition of a solid long-term energy transition strategy among the communal stakeholders.
- Sub-objective 2: Review available tools and methods and their applicability with respect to community structures.
- Sub-objective 3: Transfer scientific findings and models to the needs of planning practice in small- and medium-sized communities and create a realistic data framework.
- Sub-objective 4: Practice-check the approach and evaluate experiences.

The Sub-objectives are translated into the different research questions that structure and outline the thesis' work stages. The objectives and research questions are addressed with different approaches and methods which I regard appropriate to come to meaningful results.

§ 1.3 Research questions

The research questions of this thesis are the structuring storyline along which the chapter structure is developed. The overarching research question of this thesis is: What do decision makers in small- and medium-sized communities need to become more successful in implementing energy transition processes? The primary research questions in (Table 1.2) correlate to the four sub-objectives as principal sections of the thesis. The sub-research questions can be regarded guiding questions of the different chapters. The final conclusion of each chapter shall refer back to these research questions and give insight into the findings and outcomes of the specific work sections.

PRIMARY RESEARCH QUESTION	SUB-RESEARCH QUESTIONS	METHODOLOGY	CHAPTER
Framework and background How can communities anchor and monitor long-term energy transition visions in their communal development plans?	A. What role do small- and medium-sized communities play in achieving overall energy transition goals?	Literature study	One
	B. What energy visions support communal decision-makers in defining their transition goals?	Literature study	Two
Review of Tools and Methods What tools and models are available for urban energy system analysis?	C. What tools are available and to what extent are they applicable in the context of small- and medium-sized communities and their planning authorities?	Literature review	Three
	D. What are promising developments and simplifications for the communities in focus?		
Data, Modelling and processing How can tools and models be adapted to the specific demands and boundary conditions in the case study communities to ensure long-term implementation of appropriate technologies and measures?	E. How can GIS help to understand and analyse communal energy systems?	Literature study Tool functionality check	Four
	F. What central data characteristics describe the model community of the case study?	Case study description	Five
	G. What default energy system components can represent the communal energy system with sufficient accuracy?	Literature study Literature data review Data adaptation	Six, Seven, Eight
	H. Is there a sufficient local data availability to create a specific model of the energy system?	Data review Data acquisition Data modelling	
	I. What principle scenario design is helpful to support communal energy transition processes?	Literature study	Nine
	J. What adaptations are necessary for the design of scenarios in the case study?	Case study analysis Household inquiry	
Application and evaluation How does the practical implementation of the adapted tools work in the case study and what barriers must be overcome for long-term success?	K. How does the scenario framework function in a practical case study application?	Case study analysis	Ten
	L. Do the central outcomes and messages create a useful picture to support energy transition in the community?		
	M. What lessons can be learned from the different transition projects?	Case study evaluation Expert Interview Discussion of results	Eleven

TABLE 1.2 Overview of research questions, methods and chapters.

§ 1.4 Approach and methodology

The general approach of this thesis' work tries to combine the review of the current state of scientific literature of the thematic field with the practical application and evaluation of 'real' implementation projects. This to my understanding is the most beneficial approach to scientific research in planning disciplines. Only in testing scientific findings and procedures in the real world of planning and implementation, science can contribute to the improvement of transition processes. This thesis follows this idea by using an integrated concept of theoretical reviewing and research and case study experiences (Figure 1.4).

In order to approach a complex and broad topic as energy transition processes in communities it is necessary to get an overview of the scope and context in which the research work is located. Certainly, there are numerous options to approach the stated objectives. In this thesis the initial position is that of the communal stakeholders and urban planners, who are regarded the central drivers of the transition projects. In the first part 'framework and background' premises and demands of the target groups are analysed. Since today most of the available tools origin in the scientific fields of natural and engineering sciences rather than planning, a critical review of the status quo of tools and methods is included in this section. The framework shall give an overview on the scientific background of the thesis and clarify the gaps the following work aims to close.

The central part of the thesis covers 'data, modelling and processing' and is structured in two columns. The first column covers general aspects of data acquisition and scenario building. These can be used universally for comparable projects or if there is a lack of specific information. Since the objective of the thesis is to focus on implementation, the second column puts the aspects the chapters in the specific context of the case study. This means that the general assumptions are replaced or adapted according to the local situation.

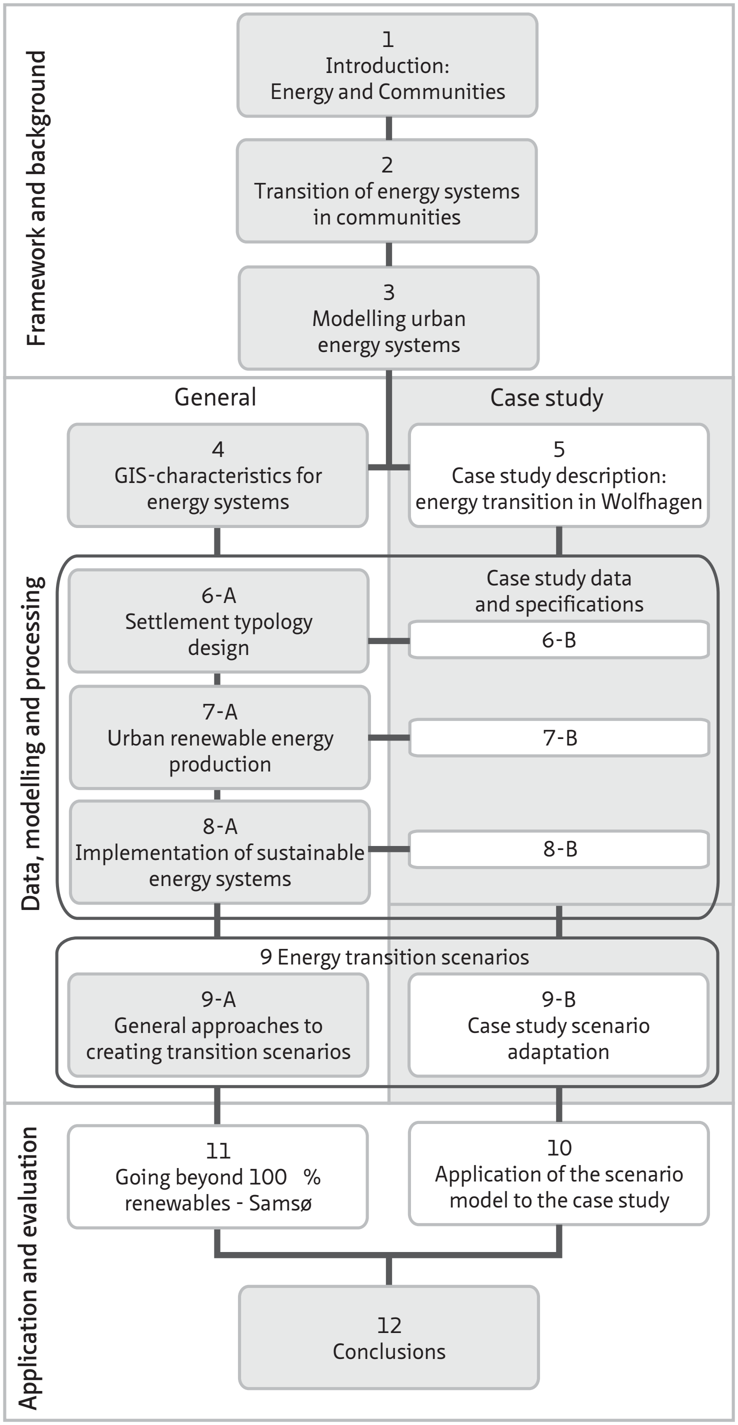

FIGURE 1.4 Thesis outline and chapter structure

In the third part the adapted procedures and scenarios are tested and evaluated. This can only be done either in parameter studies or in a real community environment. For the targeted conclusions for planning and implementation purposes the latter is the more beneficial strategy. Therefore the third part addresses the outcomes of the implementation in the case study in Wolfhagen in detail. Adjacent information is derived from experiences in other energy transition projects under comparable conditions, for instance in the case study communities of the TRANSEP-DGO project and the energy transition in Samsø, Denmark. The project framework of these case studies is described in chapter 1.6.

In the entire thesis the idea of 'exergy-thinking' serves as guiding rather new planning principle. This is because the idea of matching energy supply and demand structures in an urban energy system is regarded a plausible and easy-to-comprehend idea to illustrate highly efficient improvements in the energy chain. I am well aware that a profound and 'scientifically correct' exergy balance of an entire communal energy system is too complex to be covered in only one PhD thesis. In this thesis 'exergy-thinking' is used as a new planning philosophy rather than a method to quantify scientifically 'correct' exergy flows and losses. I regard this appropriate as a first step to introduce the principles of exergy to the target group of urban planners and communal decision-makers without overloading the approach with thermodynamic theory. Stripped to its core messages 'exergy-thinking' is useful to illustrate principles of efficient energy system modelling and local renewable energy use.

The detailed description of the methodological approaches used in the different chapters can be found in the thesis outline in the following.

§ 1.5 Thesis outline

Next to the overall description of the thesis' aims and objectives, this chapter one gives an overview on the typology of the addressed communities and the planning environment in which energy transition projects can evolve in these communities. The chapter describes the reasons why the focus is put on small- and medium-sized European communities and leaves large-scale and mega-cities out of focus. The target groups for the developed strategies and approaches can as well be found in chapter one. Basis for chapter on is a literature study in the fields of communal statistics, urban planning theory and practice and general energy policy.

Chapter two discusses two important topics at the beginning of any energy transition process in small- and medium-sized communities. Firstly the question of guiding vision to frame and structure the activities of the transition process is discussed. Chapter two analyses the argumentative and technological consequences of different energy visions from literature and realised implementation examples. The second chapter closes with a suggestion for an energy vision based on low-exergy thinking. The second topic discussed during this chapter is the configuration of a set of indicators to monitor and communicate the measures initiated during the energy transition process. The emphasis of the indicator is in this first context the question of a communicable and easy-to-comprehend tool, which enables discussion and communication for decision-makers and local actors and residents. In order to illustrate the meaning and message of the general development indicators, examples are used from the German town of Wolfhagen and the Dutch city of Almere.

Chapter three is reviewing existing tools for energy modelling and decision support. This is mostly done by literature review. The different scientific approaches to model complex systems energy systems are analysed with respect to their applicability in the focussed community categories. Most of the tools analysed are not yet used in planning and mostly base in academia. The chapter tries to identify approaches and concepts that may contribute to an improved tool for communal planners. The analysed models in this chapter have their origin in different disciplines from policy making to technical planning. The aim of the chapter is to identify existing tools that can contribute to an energy systems' approach that from the perspective of urban planning. The integration of tools into geographical information systems is considered as one step into the direction of developing scenarios in chapter nine.

Chapter four addresses the options modern GIS systems offer for the analysis and communication of energy transition processes. Other than established methods of modelling that work mostly with spreadsheets and numerical analysis, GIS offers maps and geo-referenced information. The advantages of an easy visual access, which enables laymen to understand complex contexts, may help the implementation of the methods in planning. Secondly, most aspects of energy demand and supply are connected to spatial questions. Chapter four uses a literature review to give an overview on existing GIS applications. The framework of data processing and the specific GIS data architecture structure the following data and scenario chapters six and seven.

Chapter five is dedicated to the detailed description of the German case study Wolfhagen. The elaborate description of previous developments, boundary conditions and potentials is regarded important to give the scenario model a proper context. The analysis of the Wolfhagen energy system was done in the scope of the preparatory work for the application and included the collection of data from different local sources and on-site data acquisition. The case study described in this chapter is based on the development process of the energy transition project over the past four years. The scope is on the entire community and a broad range of topics connected to energy efficiency and renewable energies. Several workshops with decision-makers have been held and the energy system of the community was analysed on an overview basis. Additionally a communal household inquiry was done to collect data on energy consumption patterns and the populations' opinion towards efficiency measures and new technologies.

Chapters six, seven and eight are subdivided methodologically in a general section and a section which is specifically dedicated to the situation in the case study. In the general section, the options to collect and acquire data from statistical sources, typologies and simulation data are elaborated. These are the data sources that are used in the model if there is no specific data available. Since the model should work for communities without too much time consuming data collection, the general data may serve as first approximation for the transition model. The central technical elements with which communities can influence the energy transition process are described as technical modules with the characteristics relevant for the model and the scenarios. Chapter six covers the urban morphology aspects with the aim of creating a demand side model of the urban building structure. The topic of chapter seven is the exploitation of renewable energy potentials for the urban energy system. Chapter eight covers technologies which allow a better matching of the demand and the supply side. The question of how non-technical data as life-styles, milieus and demographic aspects affect the energy system is covered in chapter eight as well. In all three chapters the geographic relevance of the different modules are described to indicate the potentials of the GIS described in chapter four. In the application of the model specific data of the Wolfhagen case study will be used. The second section of the chapter therefore contains the case-study specific data. The Wolfhagen data is derived from different sources, for instance community statistics, on-site data acquisition, interviews and the evaluation of a household inquiry.

Chapter nine covers scenario-building as a tool to create a transition pathway. In the first section a more general overview about the principal targets and messages of scenarios is given. This is derived mostly from literature. The scenarios that are described represent development typologies, similar to the energy supply strategies developed in the Transep-DGO project. The scenario descriptions are meant to visualise the potentials of information generation from a multi-level energy GIS. The focus here is not on a precise prediction of energy demands but on the visualisation of interaction effects between the different modules relevant for planning and decision making processes. To get useful specific scenarios for the case study, some alterations have to be made to the general scenarios. This is to create a distinct picture of the communities' transition process that can be used for decision making and communication. The influence factors for the alterations to the general scenarios are local priorities by the representation of specific target groups and stakeholders to make the transition process work.

In chapter ten the case study scenarios are filled with the data and boundary conditions of the case study in Wolfhagen. The scenario is anchoring in the planning of measures for the research project and their effects. The central question to be answered in chapter ten is to what extent the indicators are affected by the taken measures. Different degrees of impact are assumed centred on the core measures of the project: energy efficiency in the existing building sector, extension of the renewable energy production of heat and electricity and the implementation of 'smart' connections.

Chapter eleven, the first chapter of the conclusions, contains an interview with Søren Hermansen, the Director of the Energy Academy in Samsø, Denmark. The small island of Samsø has succeeded in an energy transition process towards nearly 100 % renewable energy supply within the short period of one decade. From the similarities and differences between Samsø and Wolfhagen interesting conclusions can be drawn for the future development of the Wolfhagen project as well as inspiration for communal decision-makers of small cities.

Chapter twelve contains the final conclusions. The outcomes of each of the stated research questions are summarised and a discussion of the outcomes completes the thesis work.

§ 1.6 Project framework

This PhD research was carried out in the framework of two long-term research projects. One of the projects was carried out in the Netherlands, the other one in Germany. Working on related topics in two different countries was a specific challenge. Both countries have professed ambitious targets regarding energy efficiency and CO_2-emission reduction. The consistent exploitation of renewable energies is a declared political goal. The focus on the development of energy transition in communities and regions is also a common approach in the research agendas in both countries. The two research projects were developed in this context. The central aim in both projects is to supply communal decision-makers with tools to facilitate energy transition.

§ 1.6.1 Transep-DGO

The aim of the Transep-DGO energy research project (Transep-DGO is an acronym for the Dutch 'Transitie in energie en process voor duurzame gebiedsontwikkeling') was to analyse the central steps within the process towards a sustainable community development. The target is to achieve energy-neutral districts in the course of the energy transition process. The approach based on two columns: the technical aspects of appropriate energy concepts for the districts and the procedural aspects to enable implementation for the decision-makers and stakeholders. The project focused on the development and improvement of tools for both aspects to support the process of energy transition. The project was funded by NL Agency, of the Ministry of Economic Affairs, Agriculture and Innovation1, in the framework of the energy research funding for long-term-research.

Work package one (WP1) of the Transep-DGO project focused on the procedural aspects of energy transition. The large number of available technologies, policies and financial instruments makes the management of energy transition projects very complex. The research of WP1 was dedicated to the development of steering instruments for networks and decision-makers in energy transition projects. In interviews with the representatives of the case studies barriers and approaches for better steering were identified and transferable concepts were developed. WP1 was carried out by BuildDesk[2], DRIFT[3] & IVAM[4].

The goal of work package two was to develop tools to facilitate the implementation process and to collect and evaluate the needed information. The tools were supposed to offer proper information for the different levels of involved parties, from the superordinate national level to the project developer. In the tools the results from the other work packages were integrated to achieve a good overview over the different aspects and their correlations. The work was mainly done by CHRI[5], IVAM, PGDEPW[6], TNO[7] and TUD[8].

In work package three a number of energy concepts was elaborated on the basis of the boundary conditions of four case cities and their specific boundary conditions. The target was to develop a concept to achieve CO_2-neutrality in an ecological, economic and socially acceptable way by 2050. To achieve this, the demand side and the

1 Agentschap NL, Ministerie van Economische Zaken, Landbouw en Innovatie

2 BuildDesk, Delft

3 The Dutch Research Institute for Transition (DRIFT) at the Erasmus University Rotterdam

4 IVAM UvA BV spin-off consultancy from the Interfacultaire Vakgroep Milieukunde (IVAM) Universiteit Amsterdam

5 Cauberg-Huygen Raddgevende Ingenieurs BV (CHRI), Maastricht

6 Projectgroep duurzame energie projectontwikkeling woningbouw (DEPW), Voorburg

7 Netherlands Organisation for Applied Scientific Research (TNO), Delft

8 Technische Universiteit Delft (TUD)

supply side have to be coupled in smart system combinations. For transferability the concepts were summarised in six principle supply concepts based on solar, biomass and geothermal energy for the dominant renewable source and an all-electric, a conventional and a hydrogen development strategy. This work package was contributed by ECN[9], CHRI en TNO.

The last work package covered the case studies analysed in the project. The scope of the project was not entire cities but different development areas, for instance conversion areas, new residential developments or large-scale refurbishment projects. For fifteen community and city projects in the Netherlands, interviews with the responsible stakeholders were analysed. Four communities Almere, Apeldoorn, Nijmegen and Tilburg were involved more intensely in the project as pilot communities. For them more detailed analysis and concepts were elaborated and discussed with the stakeholders. Work package four was mainly contributed by DRIFT, Hogeschool Zuyd, CHRI and TUD. The results from the three other work packages were used for the pilots to test the applicability in practice. Results and reports of the Transep-DGO project can be found on the project website (www.duurzamegebiedsontwikkeling.nl).

§ 1.6.2 BMBF Wettbewerb Energieeffiziente Stadt "Wolfhagen 100 %EE"

In the summer of 2008 the German Federal Ministry for Research and Education launched a nationwide competition for the best approaches and ideas for communal energy transition strategies. Communities and cities could apply with their ideas on improved energy efficiency, enhanced integration of renewable energies and new energy services. All communal sectors and energy uses were addressed. The cities' energy systems should be regarded in their complexity and interaction. Out of 72 proposals fifteen promising concepts were chosen to further elaborate their ideas over a period of one year. On September 27th, 2010 the German Minister for Research and Education, Annette Schavan, announced the decision of the jury. Among the winning concepts of Essen, Stuttgart and Magdeburg the two small communities of Delitzsch and Wolfhagen convinced the jury with their ideas.

After the finalisation of the formal application process for a research project, the community of Wolfhagen could start the implementation of the project ideas. The research project consists of five modules. Module one contains the overall project coordination, the monitoring and evaluation, and it is carried out by the Fraunhofer

9 ECN is an independent research institute for renewable enrgies (ECN), Amsterdam

Institute for Building Physics. Module two contains urban restructuring and refurbishment projects under the coordination of the City of Wolfhagen. The local utilities are in charge of module three and conduct a local field-test on Demand-Side-Management and local development and integration of renewable energy production. Module four is concerned with the integration and communication processes with the local stakeholders and residents and is carried out by the local energy agency. The fifth module is working on refurbishment strategies for the building sector and education and training of local planners, craftsmen and disseminators. This module is coordinated by the Centre for Sustainable Building at the University of Kassel. The detailed description of the case study can be found in chapter four.

The project is totally funded by 5 million euro and has a duration of five years. The results from all five cities are gathered and evaluated by a secondary research team, assigned by the ministry. The project coordinators cooperate with the research team to ensure the transferability of the results and the approaches.

§ 1.6.3 Involvement, approach and timing

This PhD work was made possible by funding from the EOS LT: TRANSEP-DGO project at the Delft University of Technology. The funded PhD position enabled a 50 % employment over three years with the target to finish a PhD thesis in this project framework. The involvement in the EOS project was mainly defined by the work programme of the TU Delft at the Section of Climate Design. In close cooperation with Cauberg-Huygen Raadgevende Ingenieurs b.v. the work concentrated on contributions to the tools development in work package 2 and the contribution of the Wolfhagen case study in the scope of work package 4. As complementary scientific work the PhD thesis contributed with basic chapters on tools, methodology and indicators to the goals of the EOS project.

Working mainly from abroad, the options for direct involvement in the project, especially in the work on the case studies, were limited. To get insight into the process of the Dutch communities and to keep contact to the researchers in the Netherlands, workshops and presentations were attended and an update on the progress of the PhD work was given where appropriate. The central link to the project was established via the TU Delft, where regular meetings were held to discuss the progress of work. Certainly such a detached work mode is sub-optimal for the work on a complex research project. Nevertheless, a good communication and clarification of expectations and contributions could be achieved in the course of the project. The project duration of the EOS project was August 2008 until August 2012. The PhD involvement in the project started August 2009 terminating July 2012.

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To enable employment at the TU Delft on a part time basis, the employment for the Fraunhofer-Institute of Building Physics in Germany was continued but reduced to 50 % as well. In the scope of this, the application and work on the German case study project was accomplished. The perspective to contribute a German case study to the progress of the EOS work programme was tempting, because it would add another perspective from a different country. At the same time the main focus on a German case study for the PhD work proved the only practical way of acquiring the necessary data and performing the on-site analysis. While the EOS communities were analysed and assisted by the Dutch researchers from Erasmus Universiteit (DRIFT), TU Delft, Hogeschool Zuyd, BuildDesk and Cauberg-Huygen, the focus of the PhD study was to contribute to the EOS project with the German case study of Wolfhagen.

In the summer of 2008 the Wolfhagen project was at its very beginning, with an unclear outcome of the competition. The final decision on the winning communities was made September 27th, 2010. Until then conceptual and preparatory work was done on a small-scale funding basis. The full funding of the project commenced the 1st of April 2012 with more than one year delay because of administrative and procedural reasons. This also meant a significant delay for the outcome analysis of the case study of Wolfhagen in the framework of the PhD research.

At the current state of work the EOS project has been finished. The results and experiences found entrance in the PhD work as far as possible. The outcome of the PhD research study will be the basis for the scenario and modelling approach in the Wolfhagen case study, which is now under progress. Since the implementation phase in Wolfhagen has just begun, conclusions can be drawn only from the preparatory phase of the Wolfhagen project.

§ 1.7 Scope, limitations and boundary conditions

This dissertation is situated at the intersection between planning, technology and policy and aims to mobilise the strengths and synergies that lie between these disciplines. At the same time a close collaboration between science and practical implementation is aimed at to improve the realisation of energy transition processes with long-term implications. To approach a complex topic as energy transition the focus limited. Energy can be related to every aspect of our social and economic life. To create a manageable scope I concentrated on the most relevant demand sectors of a rural community.

Cooling demands were neglected, because of rather small impacts in the overall energy balance. Where cooling aspects became relevant because of synergy effects, they are described on a quantitative basis. To enable effects on a rather short-term basis and to support transition action, I concentrated on the 'low-hanging fruits'. It has to be stated that in small- and medium-sized communities the prevalent technologies are far from being exhausted. Due to the high relevance of communication aspects, the focus is not so much on innovative future technology, but rather on the broad implementation of market-proven solutions. This is also important to address and convince a rather traditionally thinking conservative clientele. In small- and medium-sized communities highly innovative and risk-taking groups are rare and only in exceptions leaders of public opinion. Because of the small and familiar structures it is important to convince the local leaders and speakers. The transportation sector is neglected because of the difficult data situation. Solutions for transportation problems in connection to overall energy system, such as e-mobility in connection with plus-energy houses is regarded a niche solution for new buildings in the near future. Because of the dominance of the existing building stock in the case study there is only little focus on new high-tech developments. Sustainable development in its long-term perspective always raises questions of life-cycle costs of the implemented technologies, products and materials. A lot of research work is being done in this field around the world. I have not included questions on life-cycle costs in this dissertation to limit the complexity of energy discussion. To fully integrate life-cycle considerations would have meant an extraordinary effort to collect data. The topic may be included in the models and scenarios in the future when the data situation and public discussion of the issue has advanced further.

The boundary conditions of this dissertation are defined by the close involvement in the ongoing research projects and their scopes and progress. The final results of projects with a certain complexity are clearly the success of many. Wherever the results come from other sources, I indicated the authors. I hope that the work of this dissertation contributes to the implementation of energy transition processes in small- and medium-sized communities in return.

2 Transition of Energy Systems in Communities

"It is when the hidden decisions are made explicit that the arguments begin. The problem for the years ahead is to work out an acceptable theory of weighting."
Garrett Hardin, The Tragedy of the Commons, Science, Vol. 162, December 1968

§ 2.1 Introduction

The threats of climate change and the depletion of fossil fuel resources put increasing pressure on the political initiative and measures of city and community governments. The transition of energy systems towards more sustainable and secure energy supply solutions has to be solved on local and regional level. Communities play an important role in the planning, management and realisation of long-term energy transition processes. They are the link between political ambitions and the practical needs of local economy and residents. To initiate an energy transition process and anchor the goals in a communal roadmap the local decision-makers need a long-term vision of where they want to go. This is common planning practice for long-term urban development strategies. The energy issue is fairly new on the agenda and there are not many successful examples of implementation of energy transition planning in small- and medium-sized communities. The research question of this chapter is what energy visions support the communal decision-makers in defining their transition goals. The 'new' energy transition towards sustainable and CO_2-free energy systems differs from past energy transitions because the central drivers are different. Therefore new communication strategies are needed. To talk about the goals and targets is an important aspect of communication and local acceptance. Different vision statements and their consequences for transition strategies are analysed. This chapter outlines three principal energy transition visions, which may serve as guidance for the development of measures. Each vision correlates to popular maxims of energy transition discussed today. Generally two principal approaches to the problem of energy transition can be identified. The first is claiming the radical reduction of energy consumption in the developed countries, the decarbonisation of economy and a change in lifestyle. The second fraction claims that we don't have an energy problem. The only problem is the use of fossil fuels as dominating energy resource. If we used the tremendous potential of renewable energies the quantities become less important. Certainly these are exaggerated absolute positions. Most experts agree that the truth is probably that we have to do both. Still there are these argumentations going on, when discussing the issue on a more unprofessional stage with local residents and politicians. This chapter is meant to clarify the argumentation lines and put some reference to them. The first vision leads the focus on energy efficiency, the aim to reduce the energy demand as much as possible. The second vision is focussing on the production of renewables energies to the maximum possible degree. A third approach opens the view towards a more integrated energy system. The indicators developed in the second section of the chapter can serve all the vision targets in monitoring and communication.

§ 2.2 Methodology

The research in this chapter is based on literature analysis and evaluation of present trends in energy transition processes in communities. From this the three principal approaches were developed and appropriate indicators were defined. The third vision of 'smart energy communities' follows the research priorities of my long-time work at Fraunhofer in many national and international projects. The three principal development visions of this chapter serve as guiding principles for the scenarios in chapter nine. To measure success and development indicators for the monitoring are necessary. Since the new energy transition is a mainly politically driven process, indicators help to communicate and monitor the success of the measures. The chapter develops a set of indicators for small- and medium-sized communities to show the forthcoming also for non-experts on a community scale. To create a more diverse picture on the development of communities, the indicator-set includes 'classical' development indicators as well as indicators that reflect the state of the energy system's performance. The data to fill the indicator set is given in chapter six, seven and eight. For the application of the scenario model in chapter ten, the energy visions serve as the three development paths. The indicator sets are used for the display of the progress.

§ 2.3 Energy Transition

Transition has been taking place continuously throughout the development of society. Some transitions appear to be sudden changes from one state to another, but most transitions are rather slow movements that are not recognized radically by the majority of people. Energy transitions in the past have mainly been slow transitions from traditional fuels, such as wood, to fossil fuels. A lot of research has been conducted on the preconditions and circumstances that enable energy transitions. Exemplarily Fouquet (2010) shall be mentioned in this context, who gives a holistic overview over past research and publications and a detailed analysis of the historic energy transitions in the UK.

The motivation of past transitions was mainly driven by the ambition to supply better and cheaper energy services to more people. Electrification offered much better lighting qualities than gas-lanterns did. Central gas-fired heating systems offered a great step in heating comfort, indoor and outdoor air quality compared to previous coal furnaces. The broad success of the past energy transitions were mainly initialised by direct benefit for the users. For this increased benefit, they were commonly willing to pay more money. This made investments and the implementation of new technology profitable for suppliers and from the niche markets the penetration of the market accelerated with falling prices. In the course of the past energy transitions a lot of effort was put into improving the conversion technologies. Nevertheless Fouquet (2010) showed that these past transition processes took between several decades to two centuries from the diffusion of the technology to its dominance in the market. Compared to the heating systems of the 19th century, the heating systems today, even when based on fossil fuels, are clean, nearly free of dangerous fine-dust emissions, low-noise and reliable. The situation we face today has totally different boundary conditions.

The necessity for today's energy transition does not come from practical shortcomings of technology but from the threat of a global climate change and weather out of control, caused by excessive CO_2-emissions from the extensive use of fossil fuel reserves. On a more local level, this means greater risks of excessive rainfalls and flooding or heat and draught spells in some areas. The nuclear catastrophe in Fukushima has created a global sensitivity for the risks and threats of nuclear technology as well and the unforeseeable consequences of nuclear fallout. This makes nuclear energy a fade-out technology and no solution option for the next generations energy systems. The public and political awareness regarding the necessary energy transition towards a more sustainable and renewable energy supply has risen in the past decades and numerous front-runner cities have achieved remarkable successes. At the same time the time-frame outlined to accomplish the transition is rather short. Compared to former technology-driven energy transitions this makes a fundamental difference. In former energy transitions the added value for end-consumers was mostly evident. The communication and marketing of the new technologies could focus on extra comfort and better performance.

The necessity of energy transition today is still ground for scientific and political dispute. The target to reduce the emission of greenhouse gases and to reduce the risks of dramatic climate change does not affect directly the way consumers use energy. The risk of negative effects due to climate change is a public concern, while the energy prices are private, a free-rider problem. Successful urban sustainability projects for this reason aim at an anthropocentric view to start from. Only personal involvement and the focus on additional personal benefits can trigger the investments that lead to significant success on a global scale (Roorda *et al.* 2011). In his influential report Stern (2007) concludes that the necessary investments to prevent or at least limit negative impacts of climate change fall below the necessary spending to deal with the consequences. Energy transition today therefore is a precaution measure against future developments and a matter of risk limitation rather than a reaction to actual problems. Political target definition then becomes a central linchpin in transition management. The dimension of the challenge nevertheless requires a broad participation of actors from all sectors and forbids a mere administrative or legislative approach.

Basically there are two options for communal stakeholders and politicians to deal with the challenges of energy transition: either to react when problems or supply shortfalls occur, e.g. by paying transfers to people affected by fuel poverty, or to choose a pro-active strategy and to initiate the development of an energy system transition that will be able to avoid future pitfalls. Both strategies bear risks: the first in misjudging the risks and high investments for adaptation later and the second in misjudging the developments and high investments for structural changes now. In the first case this means: do nothing, maybe pay later, in the second case: pay now, maybe benefit later. The transition strategy additionally bears the risk of being overrun by global developments, e.g. negative developments on the stock markets and financial crises, on the way.

The question on how energy prices, political boundary legislation, extreme weather occasions and fossil fuel production will develop in the future has been a continuous discussion among experts in the field for decades. The risk analysis for investments in energy transition measures has to be done by the political decision-makers. The steering and management of the transition process afterwards must be clearly communicated and promoted consequently. In the following chapter I develop some practical ideas for new approaches regarding visions and monitoring tools in the urban planning process. The target to anchor energy transition first on the "regime" level consequently might enable a quicker transition also on a broad implementation basis in the short time frame left. This approach enters the transition discussion from a less socio-economic but rather urban development background, being well aware that in practice both disciplines meet in a "messy, conflictual, and highly disjointed process" (Meadowcroft 2009).

§ 2.4 Energy visions for communities

Concepts for city or community development are vision statements and guiding principles for the overall development of the city or community. They try to define binding pathways and fields of activity and the goals of future development. Typical city development concepts have a strong geographical reference and imply statements on social and economic aspects for urban planning. Following the German urban planning tradition, these concepts are commonly realised by the city's planning department who involve other experts and the public. Integral concepts for city development go one step further and try to cover as many aspects as possible and reach a higher degree of detail and a closer cooperation between the different interest groups and stakeholders. For Germany, the procedure of the planning and public participation processes on different regional scales are formally defined in the German national Regional Planning Act and the enactments of the Federal States, who are the implementing planning authorities. The urban planning traditions in Europe differ because of legal principles and institutional competences and cultures in the European regions (see Healey and Williams 1993; Marx 2003). The procedural link of energy transition projects to formal urban planning differs consequently from country to country. As a common principle, the energy development concept is a long-term guiding principle for the measures and strategies implemented by the different departments and stakeholders involved. The process of defining integral concepts for city development can either be formally described in municipal regulations and guidelines covering urban planning e.g. Freistaat Sachsen (2005), complan GmbH (2006) and Gruehn (2010) or as detached development plans concentrating on sustainability or energy issues, e.g. City of Portland and Multnomah County (2009), The City of Copenhagen (2009), Göteborg Energi AB (2011). No matter what concept and strategy is chosen, a vision and strong determination of all involved parties are essential elements.

To start an integral process on energy transition, guiding principles based on energy should be anchored in the urban development concept on a broad basis. Ideally the energy aspects are included and developed parallel to the integral development concept. Energy affects all communal fields of activity to some extent; energy transition processes will therefore have some impact on most communal fields of activity. In the past years numerous communities or cities have chosen energy visions as overall marketing headline. Freiburg in southern Germany is only the first to announce itself 'solar-region'; numerous followed. Ambitious energy visions have sprung up during the past years: 'Zero-energy-city' (Masdar City), 'Carbon neutral city' (Copenhagen), 'Greenest city in the world' (Vancouver). Many other cities proclaim similar headlines for their energy or climate action plans. These are the motto-headlines for the cities' visions and the overall direction planning and measures should be directed to.

To start communication on a long-term transition process, a strong and meaningful motto and vision can be helpful to create attention and commitment. If the vision can be transported easily and covers the central and consented targets it helps to motivate people to do something to reach the goals. If the visions are broad enough to cover many aspects, many actors can get involved. At the same time visions should include achievable sub-goals, to enable celebrating when successful steps are taken. The visions can be rather abstract, but should include a concise "philosophical" backbone that will be valid for all sub-goals. This is to prevent a single-targeted orientation of measures. In the following passages the typical characteristics of some energy visions are described. The definition of one common vision should be carefully weighed, because once published and communicated it is difficult to alter. The vision and the guidelines for the transition measures should not conflict and have a strong correlation. Visions can be optimistic and of course "visionary", if they are too featureless they cannot fulfil their binding mission.

§ 2.4.1 'CO_2-neutrality' – the super-vision?

The responsibility of the industrialised countries for the current development of the climate crisis is beyond question. After the first World Climate Summit in Rio de Janeiro in 1992 the urgency of climate change, rising global temperatures and the global responsibility of the industrialised countries led to a cautious optimism that action would be taken on all levels of politics and society. The Declaration of Rio clearly addressed the responsibility of all societal groups and in the following years broad and colourful initiatives were started by residents, local interest groups, communal administrations, schools and individuals. Often these Agenda21 activities were motivated by a strong feeling of responsibility towards the global climate situation and environmental issues. These idealistic approaches dominated in the early years over economic or financial motives. Today, more than twenty years later, this idealistic view seems to have faded and dispersed to a niche of activists. The last UN Climate Conferences in Copenhagen in 2009 and in Durban in 2011 have left the impression that a break-through for an international consensus on a follow-up of the Kyoto-protocol is unlikely. On the global and national platforms other, more urgent and pressing, problems such as the financial crisis in Europe and the US have taken the medial space of climate change discussion. Climate issues seem to become luxury problems compared to the economic and financial turbulences in the world's markets. The director of the Max-Planck-Institute for Meteorology Jochem Marotzke recently stated in an interview that the political interest has noticeably decreased over the last year (Traufetter & Schwägerl 2011) despite the alarming record of CO_2-emissions reported by the US DOE (Boden & Blasing 2011) for 2010. Even IEA, an organisation not commonly known to agitate climate change alarmism, starts its latest issue of the World Energy Outlook by stating *"There are few signs that the urgently needed change in direction in global energy trends is underway. … Despite the priority in many countries to increase energy efficiency, global energy intensity worsened for the second straight year."* (OECD / IEA 2011).

This situation leads to the question, whether it is a good advice to base communal energy transition solely on a vision of fighting climate change. The mission statement of the Climate Alliance of European cities based in Frankfurt, Germany, is about both solidarity with indigenous people in the rainforests of the world and about a commitment to fight climate change. According to Climate Alliance the number of cities, communities and other organisations registered as members was 1,600 from 18 European countries in 2011. One could read this as a great success of common commitment to the vision of Climate Protection throughout Europe. On the other hand the measures and actions that should be taken by the members are rather indicative and informative. Therefore the membership itself does not tell much about active action or initiatives in the communities. A similar initiative on a regional level was started by the government of the state of Hessen, Germany, in 2009, "Hessen aktiv: 100 hessische Kommunen für den Klimaschutz". The project is coordinated by the Ministry for the Environment. Participating communities had to sign a Charta, which states the missions and goals of the initiative. By the end of 2011 the project website www.100kommunen.hessen-nachhaltig.de lists 117 undersigning communities. On the same website only three examples for communal action and measures are published.

Climate Protection is obviously something that is easy signed and quite difficult to realise. This also reflects on a more individual level, when people are interviewed about their attitudes towards Climate and Environment Protection, about energy-saving and personal CO_2 emissions. A representative study conducted regularly every two years on behalf of the German Umweltbundesamt on the environmental awareness of German residents has found out that environmental and climate issues still get high priorities. On the question "What, do you think, are the most important problems that we're facing in our country?", 20 % of those asked named "environment protection" as most or second most important issue. 51 % mentioned "employment policy" and 24 % mentioned "economy and financial policy" in the two most important positions (Borgstedt *et al.* 2010). The same study evaluated the discrepancy between awareness and willingness to take action in the context of private consumption. To the statement "I specifically buy products that have little environmental impact in production and use." 67 % of those questioned agreed or even fully agreed. The authors of the study commented that here obviously the social expectancy plays a significant role in answering, because the results do not reflect the market share of ecological products at all. The measures people stated to have personally taken already emphasised this impression (Table 2.1). Well-established and low-cost measures have even gained impact compared to the previous survey, while measures that mean extra investments and more effort still only hold very small shares, although with some growing tendencies.

	STUDY YEAR	
Answers in %	2008	2010
Keep different wastes separately and return them to the appropriate waste systems	-	90
Turn-off unused appliances and lights	74	83
Buy energy-efficient appliances	53	65
Buy green electricity	3	8
Invest in renewable energies, e.g. installation shares, funds	2	4
Do financial compensation (compensation payment) for emitted climate gases, e.g. in transportation	-	3

TABLE 2.1 Fields of action for personal climate protection. Question: There are many recommended measures for climate protection in the household. Please tell me for every measure if you are already doing so or are planning to do so. Answers "I do, already", comparison of studies 2008 and 2010 (from Borgstedt *et al.* 2010, own translation)

The authors of the study concluded that, probably due to the financial crisis, the importance of eco consumption has slightly decreased compared to former studies. Government and communities are seen in a high responsibility for the implementation of measures and the enforcement of goals.

The past decade has produced numerous 'CO_2-neutral communities' in Germany and Europe. Typically these communities are rural and without large industries but with large agricultural or forested areas. The CO_2 neutrality then is often based on a yearly compensation of calculated electricity and / or heat demands of the residents by local surplus electricity production from wind, solar energy and biomass. In some cases, such as in the bio-energy village of Jühnde (Germany), hardly any energy-efficiency measures were taken. The focus was put solely on the energy production infrastructure. In the case of the Danish island of Samsø electricity, heating and transportation demands are included and covered partly by CO_2 neutral fuels and renewable electricity production. The balance is levelled by the surplus electricity of an off-shore wind-park. There is no common definition of how to achieve CO_2 neutrality, what sectors to include and how to balance the allocation. Only recently Jørgensen & Nielsen have published a study on a carbon balance model for the island of Samsø which includes all elements of carbon emission and absorption (Jørgensen & Nielsen 2015). This first comprehensive approach could enable a full-scope definition of carbon neutrality. Ziesing *et al.* 2010 therefore suggest a much more detailed and differentiated approach to the evaluation and definition of measures when targeting CO_2-neutrality. Also an already in 2002 conducted study of the German Institut Wohnen und Umwelt (IWU) includes more aspects of ecological sustainability than just plain CO_2-emissions (Diefenbach *et al.* 2002).

The stated situation leads to the conclusion that communities are not well advised to base their energy transition vision on Climate Protection alone. Experience shows that sometimes the commitment to the reduction of CO_2-emissions remains a lip service when it comes to practical implementation. For ambitious achievers among the political stakeholders a more locally anchored vision might be preferable. It can be assumed that some small effect on fighting global climate change can be achieved and documented alongside, even if it might seem to be a drop in the ocean.

§ 2.4.2 'Energy-Efficient Cities' – save and improve!

'Efficiency' generally has a positive connotation. It commonly means, getting a good ratio of output per input. The Encyclopædia Britannica explains efficiency in the context of energy use as:" *the ratio of the useful energy delivered by a dynamic system (such as a machine, engine, or motor) to the energy supplied to it over the same period or cycle of operation.*"[10] There is principally no differentiation made between efficiency and effectiveness which is defined as:" capacity to produce desired results with a minimum expenditure of energy, time, money, or materials." (ibid.). In practice there is probably no clear differentiation between both terms, whereas there is a different definition in Dobbelsteen (2004). Based on the publications of Vidgen *et al.* (1993) effectiveness here is describing the compliance with long-term goals and target, whereas efficiency is merely focussing on the input-output ratio as defined above. With regard to a community, efficiency would mean that it creates a good effect from its resources. Effectiveness in the terms of Dobbelsteen means that the long-term targets are achieved. In terms of energy systems, better efficiency leads to a smaller demand of energy for the same output, work or service. Which is good but due to the strong link to processes it does not necessarily include the long-term effects. Compared to the CO_2-neutrality and the energy autonomy visions, energy-efficiency visions leave the aftertaste of accounting and technical optimisation, like an industrial 'Fordish' rationalisation process that is getting more out of a given input. Also there is no clear final goal associated with energy efficiency. From the thermodynamic perspective energy efficiency can never reach 100 %. Realistic efficiencies are greatly dependent on the regarded technology and technology development.

What characterises an energy-efficient community, then? Is it a city that does its best to improve all relevant systems and subsystems continuously? Although this is probably the most realistic and sober view on reality for a communal vision this is a quite tiring

10 http://www.britannica.com/dictionary/efficiency

perspective. There is no goal connected to it, only partial successes to politically benefit from. In principle there always remains something to improve, some better technology to implement, some process to correct.

The necessity of saving a large portion of the energy we are consuming today is common knowledge and the core thesis of all energy concepts published in the past years. The 'Trias Energetica', commonly used in many publications and projects mostly in the Netherlands (Lysen 1996), brings the energy-efficiency principle to the point: firstly the energy demand has to be reduced; secondly renewable energy sources have to be exploited; and thirdly the remaining demand of fossil fuels have to be used as efficiently and clean as possible. Other than the 'climate neutrality' the focus of the Trias is more on single processes. To reduce the demand, apply renewable sources and improve efficiencies the process has to be analysed in detail and then scaled upwards to the community level. It basically is a bottom-up and small-to-large aggregative process. An extra step was inserted by Dobbelsteen (2008) into the Trias Energetica systematic. He emphasised the importance of first maximising the level of energy recovery from the supply processes before supplying renewable energies. This approach was further developed and applied to the REAP project (Tillie *et al.* 2009). It is closely related to the methodology of Energy Potential Mapping (EPM) (Dobbelsteen *et al.* 2011). The core idea is to improve the efficiency to the maximum possible degree and to enable a renouncement of fossil fuel use. Since the efficiency approach is continuous, it offers some advantages for a long-term guiding principle of energy transition. In fact, it matches a lot better the character of communal development and societal and technological change than end-point scenarios. The city of Frankfurt a.M. addresses energy-efficiency in their development guideline: Frankfurt City of energy efficiency, of Passive-houses, of electricity savings, of combined Heat and Power are the headlines of their activities.

Change sometimes appears radical and abrupt but in reality is usually a product and result of long-term processes and successions of decision making. This is specifically true for energy systems and built infrastructure. As René Kemp of ICIS Maastricht University puts it in his analysis of the Dutch energy transition from coal to natural gas: "Such a goal-oriented transition is rather exceptional; most transitions are the outcome of the many choices of myopic actors who do not base their decisions on a clear long-term view." (Kemp 2010). Efficiency aspects are crucial elements of transition processes. The idea of a new inexhaustible clean and cheap energy source today still is utopia. To create a vision on the basis of efficiency needs great staying power from the political management and the will to put long-term process over short-term success.

§ 2.4.3 'Renewable energies community' – unlimited energy sources!

A strong vision for energy transition was created by Hermann Scheer with his first book "Energy autonomy" which was first published in German in 2005 and one year later also in English (Scheer 2007). Having a political background, Hermann Scheer was one of the central promoters of the German Renewable Energy Sources Act (EEG) in the German Bundestag. He created a vision and perspective for a full transition to renewable energy sources from local initiatives and action. His vision is grounded on a profound scepticism towards globalisation, believing that more energy independency of regions and communities will also diminish some of the harmful effects of globalisation. Energy Autonomy is indeed an attractive vision also for communal decision-makers. The spirit of liberty and freedom to take autonomous, local based decisions are core democratic values and attractive to communicate as guiding principles of local politics. The 'Electricity Rebels' of Schönau were mainly driven by this strive for energy autonomy and self-determination in regaining the power over their electricity supply from the regional utilities (Janzing *et al.* 2008). Numerous local initiatives have since been inspired by their success and initiated re-communalisation initiatives of the electricity grids and electricity supply systems. While the Schönauer parents' initiative, which started after the Nuclear Catastrophe in Tshernobyl in 1986, tried to sensitise for energy-saving and efficiency and only later commenced to consider sustainable supply, Hermann Scheer strongly focuses on the huge potentials of renewable energy sources, giving energy efficiency some reprieve. From a global perspective it is good to become less dependent on fuel deliveries from Russia, Iran, Saudi Arabia and Venezuela and to oppose the sometimes questionable political and humanitarian situations in these countries. On a national level, local energy initiatives stand against the monopolies of the large energy suppliers. More energy autonomy might enhance the supply security to some degree. Nevertheless we still remain dependent on fossil fuels for most of our heating and nearly all our transportation demands. Limiting the targets of energy autonomy to local renewable electricity production falls short of the necessity to cover all energy sectors in the transition vision. The vision of 'energy autonomy' should not lead to the delusive directive that only decentralised, local and civic measures are guarantees for successful energy transition. Productive cooperation and innovative arrangements should not blackball the existing energy infrastructure and their stakeholders. At the same time the theoretically huge potentials of renewable sources from wind and sun should not mislead to the conclusion that on the path of renewables we can stop our efforts in saving energy.

Similar to the vision of CO_2 neutrality, the energy autonomy vision implies that there is a final end-point of development. Since political leaders like goals that can be reached within their elected period, there is a risk of limiting the scope of the target to a quite narrow sector, for instance the yearly balance of electricity production via a large local wind park. Once this target is connected in public perception with the vision of energy autonomy it can become a laming millstone for a long-term transition process because it leaves little room for initiatives focussed on other sustainability aspects.

§ 2.4.4 'Smart synergies communities' - exergy thinking!

The idea of using exergy as a leading indicator for optimisation processes in communities is a rather new idea. It has been tested in several research projects with specific focus on communities and regions (e.g. EU Remining-LowEx[11], IEA ECBCS Annex49[12], Agentschap NL SREX[13], UBA Exergie-Kommunen[14]). It seems worthwhile to take a look at these principles in the context of energy transition visions for communities. An overview on the principles of exergy in planning can be found in Stremke *et al.* (2011).

Exergy, from a thermodynamic perspective, is the "ability to perform work" of an energy flow. This means that compared to standard energy balancing an additional aspect is regarded in exergy analysis: the quality of the demanded and used energy flows. A comprehensive introduction to the principles of exergy in the built environment was done by Jansen (2013). While at a first glance thermodynamics seem very complex, the core messages reflect in every day experience and makes 'exergy-thinking' a feasible approach. This can be illustrated by a very simple example: If you have a pot of hot water, you are still not able to operate a laptop, even if the energy content in kWh or MJ is the as large as in the laptop-battery. The exergy content is not the same and ability to perform work is much smaller in the water than in the chemical components of the battery. While the experience, that energy has different forms of appearance (e.g. radiance, heat, momentum) belongs to our everyday knowledge, the consistent transfer to energy concepts and planning is new. All common energy concepts do not differentiate between the kWh supplied by electricity and the kWh of heat or cold. The central idea of all low-exergy concepts is to clearly differentiate between the high-

11 EU FP6 CONCERTOII: "REMINING-LowEx: Redevelopment of European Mining Areas into Sustainable Communities by Integrating Supply and Demand Side based on Low Exergy Principles, www.remining-lowex.org

12 IEA ECBCS Annex49: "Low Exergy Systems for High-Performance Buildings and Communities", Fraunhofer IBP (2011); www.annex49.com

13 Agentschap NL EOS-LT:"Synergie tussen Regionale Planning en Exergie: SREX", Broersma *et al.* (2011); www.exergieplanning.nl

14 Umweltbundesamt: "Die Nutzung von Exergieströmen in kommunalen Strom-Wärme-Systemen zur Erreichung der CO_2-Neutralität von Kommunen bis zum Jahr 2050", www.ifeu.de

exergy energy sources, which are mainly all the burnable chemical fossil and renewable energy carriers and electricity and low-exergy energy sources, which is heat at different temperature levels. The 'quality factor' of electricity is 100 %. The quality factor of room heat at 20° C (compared to 0° C outside temperature[15]) is 7 %. From the exergy perspective 93 % of the energy quality is lost or wasted, when electricity is used for heating. The core idea of using exergy principles for energy systems improvements is to exploit energy sources that match the low-exergy heat and cold demands better and to make better use of the exergy content of available energy sources. This is of course true mainly for all heat processes.

Most renewable energy sources are low-temperature heat sources such as geothermal, groundwater or environment heat. Additionally, large potentials lie in the utilisation of existing waste-heat from industrial or cooling processes, from sewage waters or exhaust air flows. These sources have potentials that suit well the 'quality factor' needed for room heating, maybe in combination with heat pumps. High-temperature waste heat (or steam) from industrial processes or power plants can be used in several cascading steps. Step by step the high temperature source is used for demands with matching exergy levels until all exergy has been used eventually.

The vision of 'smart communities' is to make use of local low-temperature heat sources in a very efficient manner and to save the high-exergy resources for the processes they are really needed for. Different to the CO_2-vision, the exergy-vision values renewable fuels with the same high-quality factor as fossil fuels, because thermodynamically they have (approximately) the same potential. The resulting design principle, that also renewable fuels must not be wasted and be used in a very efficient way, account for the fact that also these are not available unlimited. Limited agricultural spaces in Central Europe, limited recovery-rates in forests and land-use conflicts make this a wise future-oriented principle.

The low-exergy vision combines the values of efficiency and energy autonomy with a larger emphasis on the heat demand or low-exergy usages. The common approach of energy-saving gets by the low-exergy approach a sounder scientific basis. The communities will have to pay specific attention to lowering their overall heating demand to enable the exploitation of locally available sources. The primary technologies interesting for these concepts are CHP-plants, heat and cold grids, storages and heat pumps. Bi-directional grids allow the integration of different heat sources, like solar thermal inputs. Renewable electricity production comes as a surplus of high-exergy potential to meet the high-exergy requirements. Because of the

15 The "ability to perform work" or the exergy content of an energy flow depends on the process, heat flow in this case, and the regarded "reference state" or heat sink. For a detailed explanation of the thermodynamic principles view e.g. Fraunhofer IBP (2011).

optimisation of the heat sector some pressure is taken from the large space demands of electricity production. CO_2 neutrality, this way becomes a much more feasible and cross-sectoral target. The sensible approach to high-exergy renewable fuels encourages high conversion efficiencies.

The greatest hindrance for creating a communal energy transition vision on the principles of exergy is the lack of final overall targets, since low-exergy is much like maximum efficiency in principle. The lack of commonly known sustainability buzzwords is another handicap. The approach is still quite academic and in need for further translation to political language and commonly inspiring associations. The idea of using 'low-valued' energy sources will probably not thrill investors or building owners. The idea to use local resources and to build up new energy marketing concepts based local surplus heat might well. This is why the term 'smart energy' will be used in the scenario in chapter nine. The disadvantage of exergy is that some essential questions regarding sustainable energy systems cannot be answered in thermodynamic terms: availability of resources and environmental impact. They will have to be answered by additional indicators. As well concepts that integrate renewable surplus electricity in 'power-to-heat' concepts need extra evaluation under the exergy principles.

The core message of a 'LowEx' community vision is:

"It is possible to meet the energy requirements for heating, cooling, electricity and transportation by using the local potentials in a smart and exergy-aware way."

The most important issues that have to be addressed in the scope of an integrated urban development concept that focuses on low-exergy transition is to start with a differentiated analysis of the different exergy demands and the existing supply systems. The next step is to analyse the existing energy potentials in an exergy scale. The optimisation strategy is based on a step-by-step improvement of exergy-use chains and cascading management. This can be achieved by enhancing the links between demand structures and unused exergy potentials.

§ 2.4.5 Limits for energy transition from an urban planning perspective

Municipal authorities have a strong position in any urban development process. As communal institutions they represent persistence and secure stable anchoring of visions, mission statements and measures. They are core players in the energy transition process. But certainly they are not the only players and their range of power is limited. The role of being initiators, divers and moderators in a complex process, means confrontation with manifold interest groups.

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One central problem for communities is often their difficult budgetary situation, which often limits the possibilities for financial initiative to a very narrow scope. In the past this has led to increasing outsourcing of central communal duties especially in the energy sector. Many communal utilities were privatised and electricity and heating grids were sold and hence operated by often inter-regional power companies. Often the communities do not have a directive influence on the energy supply infrastructure anymore. The implementation of energy transition projects in such a context can prove to be very difficult because often the large Energy Service Companies (ESCOs) have little interest in strengthening local energy production and a growing economy of decentral renewable energy production. Uncooperative ESCOs can be a great barrier for local initiatives in energy transition. In such a case the community has to lobby for cooperation or enable and support niche initiatives independent from the ESCO. Successful re-communalisation projects like in Schönau or Wolfhagen show that communities can gain back their energy supply infrastructure, if they are persistent enough. There are also examples of good and fruitful cooperation between medium and large-scale ESCOs and innovative energy transition projects, e.g. Felsberg (Eon Mitte AG), Stuttgart (EnBW) or Mannheim (MVV AG). So at the beginning all stakeholders should be invited to join the process. Good cooperation within the energy transition initiative facilitates the development of tailored implementation and operation strategies, because expertise from different fields can be integrated in the process development.

In addition to organisational and financial barriers that have to be overcome in the course of the process, the public acceptance is a core success factor. Here again the community is in the important intermediary position of having to guide and structure the process on the one hand and paying close attention to the public perception on the other hand. Energy transition will change to a more or less radical extent the appearance of the built and natural environment. People usually have a very sensible relationship to the appearance of their proximate vicinity. If change appears to be too radical, conflicts are likely. Local politics cannot ignore public opinion. The community has to sensibly communicate vision, process and measures at a very early stage and canvass for participation. Energy transition is a learning process in which the benefits first show some time after the realisation. Conflicts can be source of fruitful discussion if they are kept on a constructive and result-oriented manner. The community can only maintain a moderating position as long as the involved stakeholders are perceived neutral to the conflict. This conflicts with the role of active steering of an integral development process. Here an early involvement of independent process is indicated especially when sensible aspects like wind energy, biogas and urban restructuring are being addressed.

Learning processes have a risk of being counterproductive, as Jelsma (1995) illustrates: "Controversies are not problematic per se, but they are a risky way of learning. Unless controversies are managed in such a way that they yield useful outcomes, and that frustration and alienation of important actors are avoided, the learning may be

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counterproductive. If actors emerge from a controversy with adverse attitudes and negative experiences, (…) [this] can block cooperation for years." Such a blockage can lead to a sudden stand-still of the process if large interest-groups are involved. Politicians will try to avoid substantial conflicts over longer periods of time and will try to focus on less controversial issues.

For Beeck (2003) there are six essential aspects for a successful technology implementation:

- interaction with and understanding of the users
- commitment of actors to a mutually shared vision
- existence of trust-relationships and coalition building
- mutual learning
- consolidation of a new innovation network
- support and guidance from an intermediary

If these aspects cannot be secured over the important starting phase of the project, each one can become a substantial barrier.

§ 2.4.6 Conclusions for creating energy visions

The described visions can serve as guiding priniciples for creating an adjusted energy vision for the community which may include several aspects and deviate somewhat from the described stringent strategies. Nevertheless a very strict dedication to the desired outcome of a development process helps communication between different stakeholders. The vision for the communities' energy transition process should be developed in a cooperative discussion process involving all relevant stakeholders and the public. To do this development scenarios and GIS-illustration of local effects are helpful. To achieve a broad and long-term commitment to the process, it is important to take the concerns of controversial groups into account and deliver a holistic and trustworthy image of the possibilities of future developments. No municipality government will focus solely on environmental and energy issues. Success in energy transition is highly connected to sustainable developments in other socio-economic and specific local sectors of the community.

From the complex interactions and interrelationships described above a fourfold model is suggested to build a transition vision upon and is reflected in the indicators:

1 Socio-economic communal development

Cities and communities are first of all living and working environments for people. To ensure a sustainable development, living quality, health and security aspects are important aspects to consider and improve. In the competition of communities and regions the migration rates reflect to some extent how well the municipalities do in offering positive perspectives.

Under what preconditions will the community develop over the transition period? What measures support a sustainable communal development in the energy context? How do residents and local economy profit from the energy transition process?

Within this sector issues of population development and demography are addressed. The question how the local population will develop and how their needs will shift in terms of energy supply and energy services is an important issue to deal with. The chosen industrial location policy can have a significant impact on residents' migrations and attraction of young families. A vision statement such as: "We aim at becoming the regional centre for businesses in renewable energy production and services" will for instance demand for good business conditions for young start-ups and mobile enterprises searching for optimal foundation conditions not only in economic terms. A successful development policy in the economic field of business attraction will consequently affect many social and energy related issues as well.

2 Global environmental impact

Energy transition is first of all a task implicated by the pressing threats of global climate change and the responsibility of industrialised countries. From an ethic point of view the necessity to take our burden sharing in climate protection seriously is an implicit precondition for energy transition. The continuous reduction of greenhouse gases and the reduction of overall energy consumption are two essential targets projected on a global scale. It is the externalised impact of all action and measures taken locally.

Do we achieve the necessary improvements regarding the global goals? Are we following our target path?

The overall energy vision from a global perspective can be quite general, for instance "We will reduce our greenhouse gas emissions to a sustainable degree and take our global responsibility seriously." The core of the global environmental impact is quantitative and indicative, indeed. Here less the 'how' but rather the 'how much' is the directive.

3 Local energy system

The vision for the development of the local energy system concentrates on imaging the future appearance of energy supply and demand systems within the community system boundary. It internalises the view on local preconditions and improvement options. It is important to differentiate this locally anchored vision from global targets because here the local preconditions regarding the energy system and local potentials reflect.

Are we becoming better in using our local energy potentials? Are our energy conversion processes becoming more efficient? Do we make good use of our renewable sources?

Compared to the global energy vision, the visions for the local energy system have to be tangible. They are based on the local priorities and potentials, for instance "We will supply all private households with renewable heat and electricity from biomass CHPs." or "We will cover all our energy demands from our local sources." Since the vision for the local energy system reflects the 'how'-question certainly more differentiation regarding the different sectors and localities is necessary. At the same time more implementation responsibility is addressed to the transition group because the abstract targets manifest in energy system images.

4 Specific local aspects

Every community faces specific challenges. Be it because of past development shortfalls in certain areas or because of strong and influential groups of people with specific interests and goals connected with development issues. As political representation these groups can have significant influence on municipality governments. At a first glance, there might not be a direct link to the energy system transition project but the integration of a vision and target to reflect specific problems can be a matter of appeasement to prevent blockage and jeopardising the process.

How do we progress on important development issues perceived as pressing problems? How do positive developments support the energy transition process? How can we 'kill two birds with one stone' by synergy developments?

The perspective on local aspects should not be perceived negatively. If it possible to integrate pressing development issues into the transition visions that integrate more active parties and groups an additional creativity potential can be exploited. The perception that 'someone profits and others get the bill' can be avoided by strategic integration. For instance a vision could state: "We aim at an energy system in the hands and the liability of the residents and the community to guarantee stable prices." or "We will combine renewable energy production with the protection of our landscape, because it is important for our touristic development."

This group of four elementary sectors forms the overall vision guiding the energy transition process. It is important that the vision declaration is concise and without an implicit date of expiry. The visions define the target paths for the development. The achievements in each section have to be monitored, published and discussed. As the question is focussed on the process, the aim of indicators and evaluation is not 'how much' but 'how are we doing'. The question if and when the visionary goal will finally be reached is less important than the question if the implemented measures lead in the foreseen direction.

§ 2.5 Indicators for Energy Transition

When we limit the scope of view from the broad context of sustainable development to the sector of energy consumption and production we soon encounter the problem that to some extent everything is connected with energy consumption. Hence social impacts and economic consequences are inherent. In the following an indicator set is outlined that can help to monitor the strategy paths for energy transition without being too complex for a broad communication and discussion. It is acknowledged that behind the accumulated development indicators a scientific methodology has to ensure comparability and soundness of result. Nevertheless regarding the progress of energy transition in the community, the focus is laid more upon progress monitoring than on comparability and competition between cities and communities. Some commonly used indicators in the broad field of energy consumption are of course well established and practical for metering urban and communal energy transitions under the described vision frameworks. Some additional indicators are dependent on the individual target paths and development preconditions and should allow a broad degree of freedom of choice.

The central meaning of indicators in this context is communication and monitoring. To display what has been or will have to be achieved, indicators shall measure if the processes and actions lead in the targeted direction or are way off path. Commonly indicators are discussed in a scientific arena, where experts know about the limits and informative value of the results. They have experience with reference data to classify the information. Most laymen lack that kind of experience. There are some energy-related indicators that everybody is familiar with. The amount of gasoline the family car consumes per 100 kilometres is an indicator that is noticed and sometimes monitored at every refuelling stop. Most homeowners have some idea of the yearly or sometimes monthly amount of fuel and electricity they need for their homes. These are usually quantitative measures of energy carriers in the sold units. The scientific indicators, such as the energy consumption of the car in Mega-Joules or Kilowatt-hours or the emitted amount of CO_2-equivalents, hardly anybody will know, because the practical relevance of these figures is low. Outside the scientific arenas of energy experts, there is obviously some translation and simplification necessary to make the impacts of energy consumption and the effects of innovative measures more understandable and handy. Experts sometimes neglect the fact that energy for most people is not a field of interest.

§ 2.5.1 How indicators influence decision making

Taking the right decisions in the progress of an energy transition process obviously demands a lot of information from different sectors and professions. A concise indicator system should deliver a holistic picture on the actual status and the paths of different decision scenarios. To understand how decision making works, it can be inspiring to take a glimpse at scientific disciplines outside the technological fields. The research on how and why people decide in a certain way and what bits of information they base their decisions on is very broad and founded on different traditions in philosophy, psychology and economics. The idea of the 'homo economicus'[16], the human who takes the most favourable decision for himself under consideration of all the available information on a rational basis, has been questioned during the past decades by researchers in the rather young field of bounded rationality (e.g. Herbert Alexander Simon) or behavioural economics (e.g. Richard Thaler, Daniel Kahneman). Since this is a broad scientific field only adjoining the approach in this thesis, only a fillip of ideas is stated here. In 'Predictably Irrational' Ariely (2010) gives an overview on the results of his behavioural studies.

Some of his key findings are:

- People base their decisions on their personal experiences and value frameworks – not strict logic. This way sometimes irrational behaviour occurs regarded from an economic perspective.
- People are biased by market inefficiencies such as mis-pricing[17] and their personal monetary anchors[18] or references when taking their decisions.

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16 The term 'Homo Economicus' or economic man first appeared in the late nineteenth century in critics of John Stuart Mill's work on political economy. The core assumption regards man as taking *rational decisions* to achieve his own advantages and defined goals. The theory was used in numerous mathematical economic models in the 19th and 20th century to represent human behaviour.

17 Mis-Pricing in this context means, that the amount of money people are willing to pay for unknown products can be manipulated by the way of display and context-setting of the project, for instance most people will be willing to pay more for a product presented in a very exclusive and expensive environment, even if they have no reference for the 'real' value.

18 Monetary anchors are prices consumers set to decide whether an offer is expensive or cheap, for instance the question if the gasoline prices at a certain filling station is cheap depends on the anchor price for a 'typical' price

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- People tend to reduce complexity when taking decisions – not the full information range but personal sub-sets are used as bases for decision making.

This last topic of reducing complexity is very important for the question of how indicators can influence decision making. In public perception the economic growth, expressed in the development of the GDP[19], is the most important indicator for the economic well-being of a country. The GDP is of course not only one indicator but an indicator set or index. It combines hundreds of indicators on the basis of economic value of different industries, services and social sectors. It represents a reduction of complexity. By public perception a rising GDP is considered a good development, a falling GDP is regarded a signal for an upcoming crisis. Similar relevance in public perception has the unemployment rate and the inflation rate. These 'big-three' are the most often published and discussed key indicators in the media and political roundtable discussions. These indicators are well established and simple to communicate and in their condensed simplicity understood even by non-experts. Indicators are needed for decision making and the evaluation of success. Even complex political issues are in the final outcome rated by these performance indicators. Politicians therefore will promote and push measures that will help to improve the GDP development, lower unemployment and inflation rates. This is specifically true before elections take place.

The voters on the other hand will aggregate their impression on the performance according to their personal weighting schemes. This means that an additional reduction of complexity takes place adding a personal impression of the person to be elected to the overall economic and social development. The media play an important role in this evaluation. Coverage draws attention to certain aspects and issues offering a certain focus. Stakeholders and politicians like good performance ratings of their own work and will keep a close look at indicators that are under public observation. So far, the stated economic indicators (Figure 2.1) dominate the perception. Indicators relevant for energy transition often do not reflect in GDP, unemployment and inflation quickly and directly. Jesinghaus (1999) argues that we need to establish an indicator system to enable voters to judge the environmental policy performance. For this he proposes an aggregated pressure index to compete with the established indicators.

I have in mind. Anchor prices are subject to habituation, leading to the situation that we only shortly reduce our driving habits, when gasoline prices rise.

19 GDP – Gross-Domestic-Product

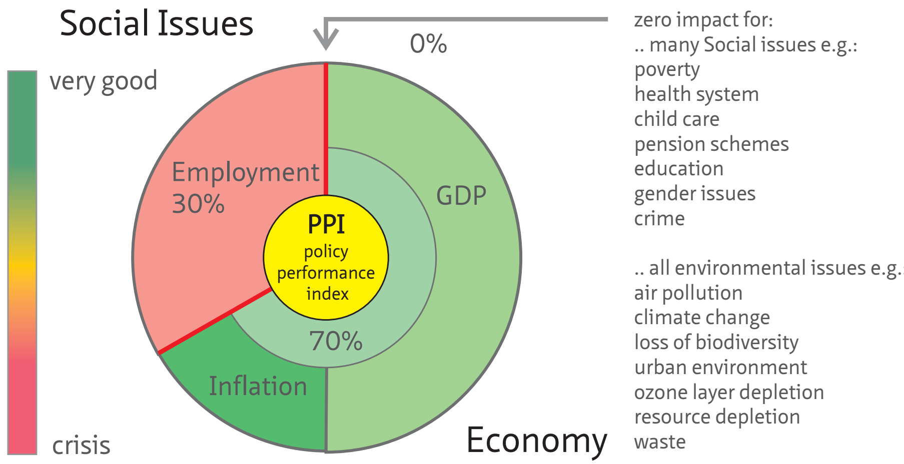

FIGURE 2.1 Reduced complexity in today's information system on political performance (from: Jesinghaus 1999)

The target and goal of an indicator system for the evaluation and monitoring of urban energy systems transition should focus on the communication of measurable and condensed information on the development of the energy system and the impact of political decisions into the picture. The idea is to offer basic status information on core development and energy-related indicators in the distribution described in 2.2.5 and aggregate the performance to an overall rating that offers first-glance orientation (Figure 2.2-2.3).

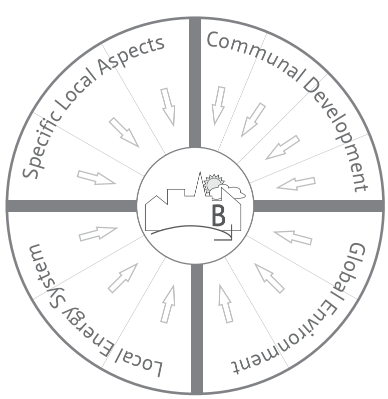

FIGURE 2.2 A set of indicators structured in the four sectors lead to an overall rating of the communal performance.

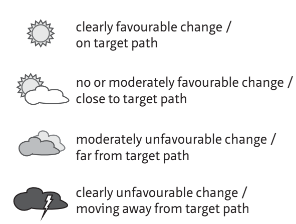

FIGURE 2.3 The direction of development on or away from the target path is nicely symbolised by weather icons, making it intuitively comprehensible (from: Eurostat 2009)

As I have stated before, the indicators are meant to monitor the development, so to speak the direction of movement of the transition process. The indicators therefore should show if the implemented measures and taken actions are leading in the direction foreseen by the vision statements. The current, yearly or periodically, state is compared to the reference state, commonly the year in which the transition started. For this a four-step 'letter-coding' ranging from D, as the worst, to A, as the best, is used. The advantage of this letter-coding is that it is self-explanatory and a similar though six-step system is already well-known from the European coding system for appliances, lighting and the energy certificate for buildings. For display the illustration and description of the Eurostat monitoring report is used, which adds comprehendible four-level weather symbols to the overall evaluation (Eurostat 2009).

In the course of defining the transition strategy the target path for each indicator is defined and argued with respect to the transition process. This is done in a transparent communication and moderation process. The starting point can be either a back-casting or a forecasting model, depending somewhat on the target definition. The results of the strategy finding process are documented and published for residents' comments. The following chapters give an overview on the indicators which will be later used for the scenario evaluation in chapter eight.

They are grouped in four sections:

- Indicators on communal development
- Indicators on global environmental impacts
- Indicators on the local energy system and
- Indicators on specific local aspects.

§ 2.5.2 Indicators on Communal Development

A number of general indicators of communal development play an important role in the evaluation and description of energy transition processes. Their descriptive nature gives an overview of the context the transition process is happening in. The facts on the general status of the community enables stakeholders and the public to reference the energy performance results. Among the many interesting development indicators on communal level, here only the most significant in relation to energy systems are stated. These are the population development and the development of the age structure in the community, commonly subsumed as demographic development, and the economic situation of the municipality reflected as unemployment rates and communal debts. These indicators give a good insight on the municipality's ability to act. The indicators described below are regarded core problems of communal development and every

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municipality is concerned with them to some extent. The overall development indicators are regarded dominant, which might degrade action in energy transition process. A more holistic view will enable synergetic approaches that show beneficial developments for all sectors.

In the section on the communal development the following indicators are grouped:

- Population development
- Development of the age patterns
- Employment
- Communal debts

Population Development

The development of the communal population is an important aspect for energy transition. While metropolitan areas in Europe still encounter a growing population, many rural areas and smaller towns already face an accelerated decrease of their population. A decreasing population has impacts on the overall energy consumption. Generally speaking fewer inhabitants consume less energy, which could be regarded a positive effect. Nevertheless this comprises the same wicked logic as the idea to reduce a buildings' energy demand by getting rid of the users. Decreasing populations are regarded a severe development problem for communities. Declining population means shrinking economic power and sometimes an overall subjective negative perception of the communities living quality. Usually real estate prices fall and the maintenance costs for energy infrastructure rise per capita. This has to be taken into account when the development scenarios are evaluated. Of course there are conditions, like the development of mega-cities, under which rising populations appear problematic as well but in most central European cities and towns the positive aspects of a slightly increasing or at least stable population prevail. The development targets for the population development depend on the overall perspective of the community. While the city of Almere aims at nearly doubling its inhabitants to 350,000 by 2030 (Benner *et al.* 2010), rural communities like Wolfhagen can be content if the population decrease stays moderate. The consequences for an energy transition process are fundamentally different in both cases and the development paths cannot be defined on one common scale. The community paths have to be developed individually for both communities (Table 2.2). In the example the level of success is related to a development period which is of course dependent on the goals and timeframe of the community.

DEVELOPMENT	ALMERE (2012 – 2030)	WOLFHAGEN (2012 – 2030)
	population 350,000 (+84 %)	slight population increase (+1 %)
	moderate population increase (+70 %)	stable population (±0 %)
	low population increase (+50 %)	slight population decrease (-1 %)
	very low population increase (+30 %)	severe population decrease (-3 %)

TABLE 2.2 Target definitions for two different community examples regarding population development.

To monitor the success over the years of the implementation the Compound Annual Growth Rate (CAGR) is used[20]. It gives an average growth rate in per cent from an original A(t0) to a target value A(t) over a given number of years (n):

$$CAGR\ (t_0, t) = \left(\frac{A(t)}{A(t_0)}\right)^{\frac{1}{n}} - 1$$

FIGURE 2.4 Equation 1

In the Almere example this would mean that to achieve a population increase from 190,000 to 350,000 in 2030 the average annual growth rate which would have to be achieved based on the calculation year 2012 would be:

$$CAGR\ (2012, 2030) = \left(\frac{350{,}000}{190{,}000}\right)^{\frac{1}{18}} - 1 = 0.0345 = 3.45\ \%$$

FIGURE 2.5 Equation 1a

20 The Compound Annual Growth Rate (CAGR) describes the average yearly growth rate of a given entity. In economics the CAGR is a key figure to monitor investments and market developments.

From 2012 to 2030 it is 18 years which shows as 18th root in the function. The actual (measured) growth rates or the development of the population can be monitored yearly and as accumulation of measured data to level development irregularities.

For the two communities stated goals could lead to the following rating scale:

DEVELOPMENT	ALMERE (YEARLY AVERAGE)	WOLFHAGEN (YEARLY AVERAGE)
	≥ 3.45 %	≥ 0.06 %
	3 % to 3.44 %	0.01 % to 0.05 %
	1.46 % to 2.99 %	-0.16 % to 0 %
	≤ 1.47 %	≤ -0.17 %

TABLE 2.3 Rating scale resulting from the defined target definitions.

The growth rates stated here for the city of Almere are rather extraordinary for a European community. In most cases a moderate rise or stable population development will be regarded positive for a sustainable development. A moderate population development, be it positive or negative, allow an effective and targeted adaptation of the energy system. Great turbulences in the population development on the other hand inevitably cause inefficiencies and unnecessary energy losses caused by too large or too small capacities. The annual population development is commonly monitored by the communal registration offices and reported to the national statistical offices, where the data can be obtained.

Development of the age patterns

The demographic change is also an important boundary condition for the evaluation of energy transition processes. Next to the overall population development demographic change includes trends of migration and the population structures. The structural changes affect the age pattern, a growing share of 'old' people in the population, a change in living-structures, a growing share of single-households, and an increasingly heterogeneous population, caused by immigration. The structural changes of an aging population are dominant for rural communities with a significant emigration rate (economic migration movements) and shall be regarded specifically in this context. On average the population in Europa is becoming older. Next to population decrease this is regarded a core problem for severely affected communities. The share of people above 65 years of age will move from approximately 20 % in 2011 to almost 35 % in 2060 by actual forecasts. Migration and demographic aspects will affect different regions and towns differently. For the first time in history the population is decreasing and aging in many regions of central Europe. Growing life-expectancies and an uneven regional distribution of the developments make it difficult to generalise the effects and useful strategies to take. The largest risk of an aging population today appears as the shrinking share of employed persons to the share of financially supported people. Aging populations are regarded economically declining populations. Obviously, if less people contribute to the economic turn-out, the economic growth cannot be maintained. Given the current boundary conditions of retirement ages, low chances for 'silver-workers' on the job market and the social security rates, the perspective is negative. On the other hand high life-expectancies come along with significant improvements in health and the number of healthy spent years, a fact that must and will reflect in the development of retirement ages and the share of people working beyond the age of 65. Although the problem is recognised it has to be solved by national legislation and policies and the options on local level are limited. Communities encounter specific problems that affect also energy transition and strategies. Aging households use more floor space per person, because often the parents remain as long as possible in the houses, while the children move out. The building structures are commonly not designed to take life-cycle adaptations of their inhabitants into account. This way, vacancies follow a period of aging inhabitants. The specific needs and changes of energy consumption patterns of older people are not yet specifically researched and documented yet. There are some studies in progress that cover these questions (Blesl *et al.* 2010). Aging populations entail changes in infrastructure. Changing housing, medical and mobility demands need to be taken into account and have to be solved by infrastructure investments. Adaptation of infrastructure is expensive for communities. While the pressure on social security systems and pension funds is usually not directly affecting communities, energy poverty of elderly people might well. On the other hand an aging population might well be a population causing less CO_2 emissions, as the research of the Department of Demography at the University of Berkeley suggests (Zagheni 2011).

Because of the existing age structure the problem of an increasing share of old-agers will be growing until 2060. Afterwards the development depends on the fertility and immigration rates. To monitor the development within the community it is suggested to monitor the old-age dependency ratio. This is the ratio of the dependent old agers to the people representing the working force:

$$\text{aged dependency ratio (ADR)} = \frac{\textit{number of people aged } 65 \textit{ and over}}{\textit{number of people aged } 20 \textit{ to } 64} \times 100$$

FIGURE 2.6 Equation 2

The limit presumes a retirement age of 65 years. Today many countries as The Netherlands or Germany are lifting the retirement age up to adapt to demographic change. Individual retirement strategies may differ from the official retirement age limits but for general strategies it is favourable to use statistical averages. For the time being the development of the aged dependency ratio can serve as development indicator. Almere and Wolfhagen have a very different population structure, Almere being a very young, Wolfhagen a rather aging community (Table 2.4).

POPULATION IN AGE GROUPS	ALMERE	WOLFHAGEN
0 to 19 years	54,071	2,566
20 to 64 years	119,640	7,507
65 and above	14,366	2,776
Aged dependency ratio	12	37

TABLE 2.4 The population in different age groups lead to different aged dependency ratios.

These different preconditions again lead to different targets regarding the evaluation of the indicators. It is assumed that a rather stable or decreasing aged dependency ratio can be regarded positive, while a rapidly growing ratio indicates a vastly growing aged population or vice versa a severely declining employed population. As a reference for the scale, the prognosis of demographic development can be used for a baseline. An increasing speed of aging is considered negative, a slowing down of aging is considered positive. The predicted population development of Almere for the year 2020 leads to an age dependency ratio of 16, for Wolfhagen the prognosis tends towards 68 for 2030. To scale the indicator, we assume that a positive or negative deviation of 5 % regarding the aged group occurs. This means that in the worst case the aged dependent group increases by 10 %, reducing the group of the working force by the same quantity. The indicator shall display a shift between age groups without interfering with the overall population development. The resulting scales are not very different regarding the yearly progression, although very different in the final outcome of the ADR (Table 2.5).

DEVELOPMENT	ALMERE (YEARLY CHANGE ADR)	WOLFHAGEN (YEARLY CHANGE ADR)
	ADR2009 +2.1 % -> (ADR2020: 15)	ADR2009 +2.5 % -> (ADR2030: 62.3)
	ADR2009 +3 % -> (ADR2020: 16)	ADR2009 +3 % -> (ADR2030: 67.8)
	ADR2009 +3.2 % -> (ADR2020: 16.9)	ADR2009 +3.3 % -> (ADR2030: 73.7)
	ADR2009 +3.7 % -> (ADR2020: 17.8)	ADR2009 +3.7 % -> (ADR2030: 80)

TABLE 2.5 Possible rating scale for the development of the aged dependency ratio

Since the data of the communities reference different target years and the monitoring bases on at least a yearly indication it is utile to base the indicator on a yearly progression. This leaves a large flexibility for the definition of the target paths.

Unemployment Rates

Unemployment rates are an indicator under great public observation and sensitivity. Unemployment is defined as the ratio between unemployed workers, who have been actively searching for a job, and the total labour force. The unemployment rates indicate how the communities' population is linked into the job market. The unemployment rates do not indicate the number of employees within the community boundaries, so the local unemployment does not directly connect to the success of local businesses, since the jobs can be located outside the communal boundaries. Secondly the statistical reference areas are often unequal to the geographical areas and only give an estimated idea of how the community is doing economically. Nevertheless it is a common and well-understood, easy to communicate indicator that will give some idea on the overall tendencies. Generally speaking, falling unemployment increases the share of income tax for the community (indirectly) and decreases the aid transfers. The development of the unemployment rates is of course only significant for communities that encounter problems with unemployment. It should be noticed that there might be a close regional neighbourhood of municipalities or regions with high and those with low unemployment. While high unemployment appears to be quite persistent, good economic development may lead to the opposite problem of skills shortages. In heterogeneous communities or communities that have encountered a severe structural change, e.g. due to the closure of large production sites and successful start-ups, high unemployment and skills shortages can occur at the same time (mismatch unemployment). If skills shortages develop to be the more dominant problem, it might replace the unemployment rate in the system. Since unemployment is still a pressing

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problem for many rural and economically weak communities positive effects for the job market might well be realised by increasing efforts in renewable energies and local efficiency businesses. It is assumed that a decrease of the unemployment rate to full employment is a desirable development. Although there is no common definition for full employment an unemployment rate below 2 % may be regarded as such. For our two example communities the unemployment rates are given as 2.9 % for Wolfhagen and 5.7 % for 2010. For a monitoring there is a target definition necessary. For Wolfhagen an absolute target of full employment seems achievable. Given the target year of 2020 full employment (less than 2 % unemployment) would mean a further reduction to get on the 'sunny side'. A still good development would be regarded to maintain the already low unemployment rate. A negative development would lead to an increase of unemployment. For Almere full employment seems rather ambitious. A decline of unemployment seems desirable and a further incline would be clearly unfavourable. Table 2.6 gives examples for a target definition.

DEVELOPMENT	ALMERE (2020)	WOLFHAGEN (2020)
	significantly falling: UER2010 - ≥0.2 %*n	full employment 2020: UER2010 - 0.1 %*n
	slightly falling: UER2010 - ≤0.2 %*n	constant: UER2010 = 2.9 %
	constant: UER2010 = 5.7 %	slightly rising: UER2010 + ≤0.2 %*n
	severely rising: UER2010 + ≥0.2 %*n	severely rising: UER2010 + ≥0.2 %*n

TABLE 2.6 Example for an indicator scale regarding unemployment

Communal Debts

An important measure of the communal capacity to act in the transition process and to trigger investments is the communal debts. Overwhelming debts hamper any public investment in the transition process. In some countries like Germany highly indebted communities loose parts of their financial decision autonomy and fall under financial supervision, which makes investments and strategic action very difficult and protracted. The raising of credits becomes difficult and costly for the community. Facing the sometimes severe effects of global financial crisis and an on-going decline in economic strength has increased the communal debt load tremendously in some regions. The average communal debts per inhabitant in the State of Hessen in Germany counted € 2,500 in 2009 with great regional differences. There are communities in

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Hessen with debts below € 50 per inhabitant as well as communities with debts over € 5,000 per inhabitant (Eibelshäuser 2011). The average value therefore does not give a good indication for the local conditions. The communities have to report and give account of their financial planning. Therefore the data is available at the communities. Positive developments in decreasing the debt load of the community might be the essential factor for the implementation of identified measures for energy transition. The positive economic effects of local energy production should reflect in this indicator on the long-term. As all of the general development indicators the financial and economic aspects should not be given too much differentiation in the indicator set, since it is focussed on energy transition aspects. Nevertheless depending on the individual rating and priority setting in the community the economic aspects can be given more room.

The target of severely indebted communities must be the reduction of the debt load. Depending on the scale of the problem efforts to reduce debts may be very dominant, which might lead to the need for alternative financial models for the energy transition investments. Very generally a step-by-step reduction of the debt-load per inhabitant can be regarded a positive (sunny or partly sunny) development. Increasing debts by deficit spending at different speeds is clearly rated negatively (Table 2.7).

DEVELOPMENT	ALMERE (2020)	WOLFHAGEN (2020)
	significantly falling: Debts2010 - ≥5 %*n	significantly falling: Debts2010 - ≥5 %*n
	slightly falling: Debts2010 – 0 to 4.9 %*n	slightly falling: Debts2010 – 0 to 4.9 %*n
	slightly rising: Debts2010 + 0.1 to 2 %*n	slightly rising: Debts2010 + 0.1 to 2 %*n
	severely rising: Debts2010 + > 2 %*n	severely rising: Debts2010 + > 2 %*n

TABLE 2.7 Example for an indicator scale regarding communal debts

§ 2.5.3 Global Environment Indicators

Global indicators are meant to give an overview on the development towards the global environmental goals. In Chapter 40 the ‘Declaration of Rio’ states the necessity for further development of concise sets of indicators to monitor the development in the different sectors of sustainability on different scales from global to local perspective

(BMU 1992). Sustainable development encloses the trias of ecology-economy-society and therefore indicators would have to cover the relationships and dependencies within this tension zone. The United Nations Commission on Sustainable Development (UNCSD) The OECD's Environment Directorate publishes an update on essential environmental indicators collected throughout the OECD countries every two years. The OECD programme on environmental indicators was initiated in 1989 to fulfil the purposes to track and measure environmental developments and to monitor and promote environmental issues in politics and economy. The indicator sets used are aligned with the agreements of the UN Commission on Sustainable Development (UNCSD). As theoretical framework for the indicator structure the OECD uses an extended 'pressure-state-response' (PSR) model[21] (Linster 2003). The core-set of the OECD contains 40-50 indicators covering 15 environmental issues, from climate change to socio-economic developments. The key-indicators dedicated to political decision-makers condense these to a dozen. The model has been further developed extended by the European Energy Agency (EEA) to a Driving-Force-Pressure-State-Impact-Response (DPSIR) model.

The complete indicator set of the EEA developed in the course of the European Environmental Pressure Indices project (European Commission 1999) contains 60 indicators in ten categories in the first publication in 1999 and was revised and improved to about 48 indicators in 2001. The latest report of 2009 presents more than 100 indicators and picks 11 headline indicators for an overall picture (Eurostat 2009). It is clear that this is information on a sophisticated experts' level. To inform communal decision-makers on the performance of their energy transition progress this is far too complex and probably an information overkill. Experience shows that the mere quantity of information does not necessarily lead to better decisions. Every decision-maker will tend to condense and simplify the amount of information to a size he or she can handle and work with.

In the case of unclear information or controversial messages one will search for more simplicity. In the following three key indicators will be described:

- Energy consumption per inhabitant
- Local renewable production per inhabitant
- CO_2-emissions

21 The Pressure-State-Response Model approach was developed in the late 1970's by David Rapport and Anthony Friend Rapport (1990) and adopted by many OECD countries in the 1990's. The PSR model provides a first classification of indicators of direct and indirect environmental pressures, indicators that describe the status of environmental conditions and the societal responses resulting from these conditions.

Energy consumption per inhabitant

The total energy consumption per inhabitant is an indicator which aggregates the demand side aspects of the energy system. The target is clearly focussed on overall reduction. Therefore efficiency measures directly reflect in the overall energy consumption. The energy consumption by different sectors is, next to the CO_2-emissions which represent the environmental impacts, a commonly used global indicator. To achieve comparable results the energy consumption is monitored in kWh per inhabitant. This means that the final aggregation sums the total final energy demand for heating, cooling, electricity and transportation in one figure. To evaluate the energy consumption per inhabitant a start balance has to be done. Since this is a process already often used, statistical values are available if there is insufficient real data. Nevertheless communities are well advised to put some effort into a good monitoring system of the demand side otherwise the results might not correlate well with the real situation. Here a 'multi-layer' concept is proposed. Where ever there is specific local data the calculations should be based on this. If there is no data available regional or national statistics can fill the remaining gaps to create a full picture.

For a long-term monitoring the demand side should be represented in a geographical database. This allows detailing data sets in the course of building and development measures without risking the integrity of the data model. Examples of demand side cadastres are geographical building typologies or heat demand cadastres (Negash 2008, Hensel 2010).

Local renewable production per inhabitant

A core aim of the energy systems transition is the increased exploitation of renewable energy sources. To meet the future energy demand an increasing share of renewable energy production is necessary. National development plans for the renewable energies have to be implemented on local level. Integrated development plans for the communities' energy system usually base on a progressive extension of renewable energy production. Especially rural communities can show quick and significant progress in monitoring the development of wind energy, photovoltaic and biomass. The indicator summarises the produced energy per inhabitant. In correlation to the local energy demand the ratio of the renewables can be monitored.

The monitoring of renewable production can be implemented in the same geo database. This is reasonable because there is always geographical impact connected to renewable energy production. This can easily be visualised in a map format. The different renewable energy sources play different role in different areas and on the level of municipalities there is often a determined priority for certain systems. The potential evaluation which is part of the strategy development process should certainly play an important role in the definition of promising measures. Energy potential mapping (Dobbelsteen *et al*. 2011) and heat mapping (Broersma *et al*. 2013) are certainly a good starting point for the transition process.

CO_2 emissions

In the context of environmental impacts of energy consumption the CO_2-emissions are commonly regarded an indicative indicator for the share anthropogenic energy consumption has on global warming development. The CO_2-emissions are consequently a powerful political indicator to demonstrate the necessity of action. They are the 'force indicator', which induces change to the state of the environment. The state of the environment, in the scope of climate change, can be indicated by the CO_2-concentration in the atmosphere leading to a measurable rise in global temperatures as indicated by the deviations from average. The impacts on the other hand are less well predictable, especially on a local communal scope. The threat of natural disasters probably caused by or at least maybe accelerated by rising temperatures are omnipresent on a global news week.

The responses to these simple indicator trends are multiple: measures for energy efficiency, energy-saving and the increase of renewable energy use can result to very different approaches on a local level and the colourful picture we see in urban planning processes today. The idea of an indicator system is to make the impacts or effects of our energy consumption measurable and to track the achieved targets. For their 2009 report Eurostat structures the issues 'climate change and energy' in one topic tracking the core indicators on three levels of detail. From level three a rather differentiated and detailed picture on the energy sector can be derived. In the more detailed report specifically targeted at energy, transport and environment issues (Eurostat 2011) a lot of information on the development of detailed energy related indicators throughout the EU27 is given.

While the greenhouse gas-emissions can be allocated to a local level using the polluter principle, global temperatures do not play a role on local level. Since there will be no measurable effect to global climate, merely the communal savings of greenhouse-gas emissions will be integrated in the indicator system. This is to represent success on a comparable and scalable level.

The allocation of CO_2-emissions can be done locally according to the fuels used for the supply of final energy consumption. This seems appropriate in the context of urban energy transition, because it usually allows a clear allocation of emissions to polluters. This approach is concise for heating, electricity consumption and transportation. It is not concise in the physical location of the emissions. The actual emissions can occur in

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great distance to the consumer who induces the emissions. Contrary to local fine dust emissions, which need to be addressed with geographic reference, CO_2-emissions can be regarded a global issue and allocated to the initiator (Table 2.8).

The data for CO_2-emissions can be derived from broadly used data-bases like GEMIS.

ENERGY SOURCE	PROCESS	CO_2-EMISSIONS [g/kWh$_{final}$]
Burnable Fuels	Heating Oil	302
	Natural Gas	244
	Liquid Gas	263
	Hard Coal	438
	Lignite	451
	Wood Chips	35
	Wood	6
	Wood Pellets	41
Electricity	Electricity Mix	633
District Heating	70 % CHP	219
	35 % CHP	313
	0 % CHP	407
Local Heating	70 % CHP	-79
	35 % CHP	119
	0 % CHP	318

TABLE 2.8 CO_2-emissions of energy carriers for final energy consumption from GEMIS version 4.5 (Großklos 2009)

The CO_2-emissions are connected to the final energy consumption, which is evaluated in the scope of a demand analysis. The overall development of CO_2-emissions should of course gradually decline in the scope of the energy transition strategy. The target path for CO_2-reduction can be either used indicatively, e.g. in the context of CO_2-reduction vision, or informative as outcome of the implemented measures. Rising CO_2-emissions always indicate that the implemented measures and actions are either not successful or other developments dominate and undo progress in CO_2 reduction.

§ 2.5.4 Local Energy System Indicators

The monitoring of the transition of a communities' energy system is a complex issue. Therefore a clear differentiation between the professional planning level and the public communication level is beneficial. While on a professional planning level a lot of detailed information and modelling is necessary for success, the amount of information for public discussion has to be simplified and of reduced complexity. For small- and medium-sized communities in this focus this applies as well for political decision making. Nevertheless the results must comply with the strategies and results from the experts' systems and tools. They have to lead to realistic and feasible results. The central aim of indicators is to keep track and communicate progress and success, to identify sectors that demand specific attention and effort. The indicator system proposed here aims at a reduced overall complexity of only two key messages regarding the energy system:

- How well are local resources used?
- How high is the import dependency?

These two indicators translate 'exergy thinking' into a communication mode that does not demand for a profound understanding of thermodynamics. To take into account the 'value' differences of energy sources for the analysis of the local energy system a simplified exergetic approach is proposed. For the evaluation two indicators are used to describe the local energy system:

- The Demand-Supply-Parity
- The Import Dependency

The concept of exergy as indicator in community energy systems

The First Law of Thermodynamics describes energy as a conserved quantity which can neither be produced nor destroyed in any process but only be converted into different energy forms. The first Law of Thermodynamics however gives no information of whether conversion is at all possible within the process. It is the Second Law of Thermodynamics which adds this aspect by giving the conversion a direction and giving information on the practicability of the process. The Second Law differentiates two principle energy classes: energy that can be converted into any other energy form: exergy (e.g. electricity or kinetic energy) and energy which cannot be converted into other energy forms any more: anergy (which is the inert energy of the reference environment) {Equation 3}.

$$\text{energy} = \text{exergy} + \text{anergy}$$

FIGURE 2.7 Equation 3

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The term 'exergy' was first introduced by the Slovenian professor Zoran Rant as early as 1956 (Rant 1956). By common definition, exergy is the part of an energy flow that is capable of performing work e.g. (Rebhan 2002). Figure 2.8 shows different energy forms and their convertibility in the context of the First and the Second Law of Thermodynamics.

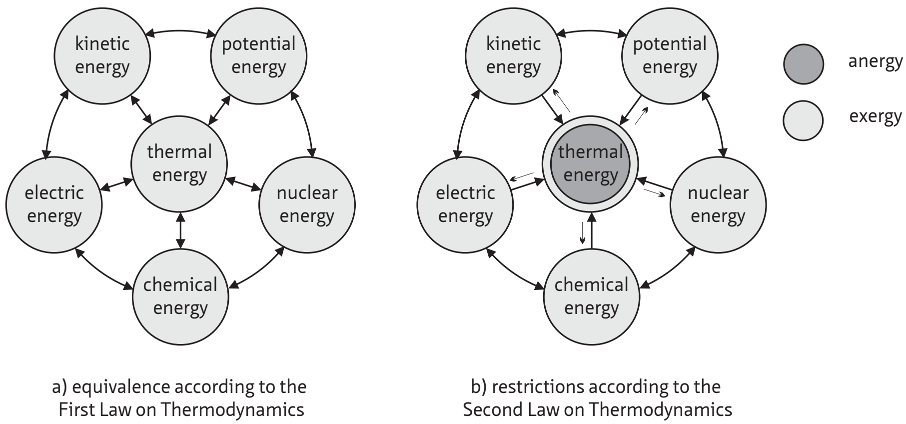

FIGURE 2.8 Forms of Energy in the context of the First and Second Law of Thermodynamics; from (Sperlich 2006)

Because of the different forms of energy it is not sufficient to characterise energy by quantity alone. The exergy concept adds the quality aspect to the quantitative energy message. In every energy process, exergy is converted into anergy. A mixture of both exergy and anergy is called limited convertible energy, e.g. heat which always contains both components. The proportion between exergy and anergy in the case of heat depends on the temperatures of the source and the environment. While making use of the energy flow, e.g. for heating a room, useful exergy is converted into unusable anergy. The energy of a 60°C heating supply becomes worthless for heating purposes as soon as it leaves through the open window above the radiator into the cold outside environment. The 'usefulness' in turn depends on the regarded process: 60°C water is useless for the preparation of a cup of tea, even if there are unlimited amounts available. The heating of houses and the use of electrical appliances does not destroy energy but converts the useful exergy part irretrievably.

As shown above heat or thermal energy is a mixture of anergy and exergy. To calculate the exergy content of heat the Carnot factor is the most important entity. It is defined for the regarded temperature T (Equation 4).

$$\eta_c = 1 - \frac{T_0}{T}$$

FIGURE 2.9 Equation 4

From this the exergy of heat results:

$$\dot{E}_Q = \left(1 - \frac{T_0}{T}\right) \cdot \dot{Q}_{th}$$

FIGURE 2.10 Equation 5

It becomes obvious that the exergy depends not only on the operating temperature but as well on the temperature of the environment. Exergy is therefore not an entity of the system itself but of the system in the context of its environment. This is a very important difference to the energy approach whenever regarding heating systems. T0 represents the environment as ultimate sink of all regarded energy processes. In thermodynamic calculations exergy can only be evaluated under defined boundary conditions (Rebhan 2002). The exergy content of a hot water storage tank will differ whether it is considered relative to a reference temperature of -10°C or +30°C. The exergy content of a heat source can be characterised by this 'quality factor' as shown in (Equation 5). Table 2.9 shows the quality factors of heat at a reference environment of 9°C as average Northern European outdoor environment.

HEAT	QUALITY FACTOR AT REFERENCE TEMPERATURE T_0=9°C
Heat at 120°C	0.28
Heat at 70°C	0.18
Heat at 60°C	0.15
Heat at 50°C	0.13
Heat at 40°C	0.10
Cold at 0°C	0.03
Cold at -10°C	0.07

TABLE 2.9 Quality factors of heat for a given (constant) reference environment.

It has been shown that the quality factor results in a negative value for temperatures at $T<T_0$ (resulting in a positive exergy content for "cold"). However, many (building) professionals are used to regard cold thermal energy as a positive value. Therefore sometimes the quality factor is placed between absolute brackets. It has to be taken good care of the direction of exergy flow in the system (comp. Fraunhofer IBP 2011 p.22).

Since there is a broad variety of energy processes in communities with different boundary conditions and reasonable reference temperatures, a full thermodynamic modelling for a community based on exergy would require a detailed and dynamic description of both processes and boundary conditions.

Exergy in the past has been used frequently to optimise the energy performance of power plants and technological processes. The optimisation of energy supply systems or buildings has been discussed in numerous papers and research projects (Torío *et al.* 2009). Only recently some international research projects have broadened the view of looking at exergy as an indicator in the context of buildings, communities and regions (VTT 2003, Sakulpipatsin 2008, Molinari 2009, Fraunhofer IBP 2011, Stremke *et al.* 2011, Jansen 2013). The problem of modelling a complex communal energy system in a common and consistent manner has not yet been solved. For the evaluation of communal energy system the added value of exergy thinking results from a simplified approach as already addressed by e.g. Stremke *et al.* (2011) with regard to planning principles and guidelines.

Exergy in communal energy planning

Energy systems in communities basically contain elements of three different exergy characteristics: electricity, fuels and heat. Electricity and fuels can be regarded 'high-exergetic' or 'high-quality' resources. They have high conversion potentials and high quality factors (cf. the approach of Fraunhofer IBP 2011 p.159). Heat processes show lower exergy potentials, wherein there are different levels of exergetic quality of heat both on the supply and the demand side (Figure 2.11).

sources	quality factor	application
fossil & renewable fuels and electricty	high	lighting appliances
waste heat high temperature	medium	cooking washing
waste heat low temperature environment & geothermal heat	low	domestic hot water heating

FIGURE 2.11 Levels of exergy-use in communal systems (from Fraunhofer IBP 2011)

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The added value of an exergy analysis lies in the identification of unused energy flows that still contain usable exergy and the creative and smart connection of these potentials to the demand side. As shown above the largest portion of demand is of fairly low exergetic quality. This way the use of renewable energy sources, including resources of waste heat and cold, becomes feasible and economically attractive compared to renewable island solutions replacing individual fossil based systems by systems based on high-exergy renewables. Regarding complex heat and electricity systems the exergy approach allows the necessary differentiation for increased overall efficiency.

In the indicator system a plain 'exergy' indicator does not give much additional information, because the transition always bases on modification or substitution of processes. In the past years there has been some aim to replace the common energy indicator systems by an exergy-based concept. Some authors as Dincer (2002) or Kilkiș (2011) draw a very optimistic picture about the informative power of exergy for politics and communal systems' planning and propose the development of exergy-based thermodynamic models to replace the current energy related approach (Jansen 2013). A very holistic approach in this direction was published by Foxon *et al.* (2010). These approaches aim at an exergetic model on a thermodynamic basis. This is not the aim here. It is rather tried to translate the core benefits of 'exergy thinking' into a practical monitoring and planning approach for communities without too much thermodynamic overhead. The aim is to translate the complex detailed thermodynamic processes behind the scenes, from the experts' scenario and modelling environment, into communicable messages for decision-makers.

The main difference and new approach for monitoring the developing of the local energy system is the insight that the common energy balancing approaches fall short in two important aspects. Firstly the energy approach neglects the qualitative character of energy. Heat and cold is not equal to electricity and natural gas. Secondly the yearly balancing modelling in common monitoring systems neglects the fact that the core challenges of energy system transition will be grid stability and energy storage because the supply or production of energy will deviate from the demand with increasing amounts of fluctuating renewable energy processes or waste heat utilisation. This is an important factor for future electricity systems as well as for local waste and renewable heat and cold grids. It is therefore important to emphasise the importance of not only for instance the exploitation of renewable energy sources but also the congruity in time of production and demand. The target of transition in the energy systems is to replace the demand driven energy systems by more flexible systems. Exergy is used at its informative core using simplified categories and matching approaches to transport useful transition messages for the energy transition to non-technical stakeholders.

Demand-Supply-Parity

As stated above the central idea of exergy thinking is to match quantity and quality of the demand and the supply side. The indicator describes how well this is achieved by the current layout of the energy system. The ideal solution is to meet existing demands with supply of matching exergy characteristics at any time. From an exergy point of view this would mean ideal efficiency with minimal conversion losses. Regarding the matching of demand and supply side there are a couple obstacles to overcome. These can be differentiated into exergy problems and problems of temporal congruence.

In exergy terms the electricity part is rather unproblematic. If there is need for electricity on the demand side, electricity has to be supplied. There are few options to substitute this high-ex energy source, e.g. by replacing electric domestic hot water boilers by district heating systems, and there is no question on what quality has to be supplied. The problems in the electricity supply are more or less efficiency problems and problems of temporal congruence. Therefore optimisation strategies focus on the flexibility of the demand side, e.g. by Demand-Side-Management systems and the replacement of fossil based electricity production by renewable sources. Temporal congruence already limits the production capacities of fluctuating renewable electricity producers such as wind turbines. If the supply exceeds the demand, production capacities have to go off the grid. The most flexible are turned off first, which often means that wind energy plants reduce or turn off their contribution to energy production to allow the inert base load plants to continuously operate. In the electricity scenarios this problem is addressed by either storage strategies, e.g. e-mobility, power to gas, or increased demand-side flexibility such as demand-side-management of household appliances. The electricity sector benefits in this respect from the high-exergy value and with that the 'multi-functionality' of the energy carrier and the existing grid infrastructure. Nevertheless the storage processes are connected with high energy losses and need new investments at a large-scale.

With heating and cooling systems the variation is much wider, both on the demand side and as well on the supply side. Heating and cooling systems are today supplied by high-exergy fuels or electricity, which makes the question of sufficient supply quality obsolete but results into bad exergy efficiencies for the conversion processes. Figure 2.6 shows the difference between the heating demand on an energy scale and an exergy-scale for the community of Wolfhagen (only residential buildings by typology).

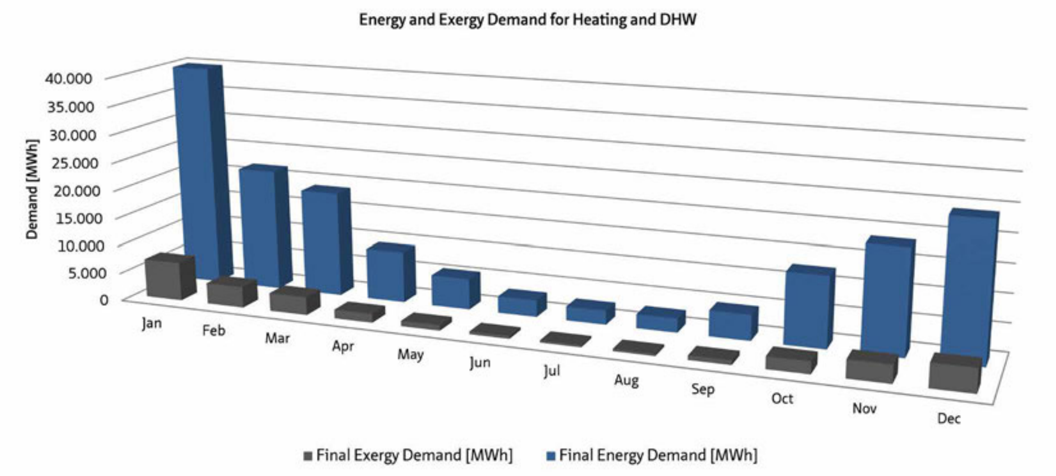

FIGURE 2.12 Final energy and exergy demands for one year for the residential building typology of Wolfhagen

In this base-case scenario the buildings are supplied with fossil energy carriers, heating oil in this case, while the real exergy demand for heating and hot water are really very small. Next to substantial refurbishments of the existing building stock, options for substantial optimisation is to replace these fuel systems with systems that supply what is demanded: low-exergy heat. In a communal energy systems there are two main sources to harvest heat and cold: the environment and technical coupling processes. Environmental heat and cold is available in large quantities with low quality. Heat and cold systems that were designed for using high-exergy fuels are usually not compatible with these low-exergy potentials. Significant effort has to be put into adaptation of technical systems.

The second obstacle for demand-supply matching is the timing. In quantity and quality terms there would be enough solar heat potential to supply the entire community, if it was only available in wintertime and during freezing nights. The same problem exists for waste heat from industrial or energy production processes, which are not necessarily available at any time they are needed. The production processes dominate the potential surplus to be used and require flexible demand side strategies. In the heat and cold supply the grid infrastructure is not available area-wide and can be the bottle-neck for exergy-efficient system change.

To monitor the quality of the local matching of demand and supply systems I propose a monthly aggregation of demand and supply which can be averaged to obtain a yearly evaluation. The monthly analysis has the advantage to show the disparities of seasonal potentials and demand structures in a more detailed way than the yearly average values. This is especially important for all solar-based systems. Figure 2.13 shows the communal exergy demand for heating and domestic hot water preparation and the exergy available from solar radiation on well-oriented roof surfaces on the residential buildings in the community.

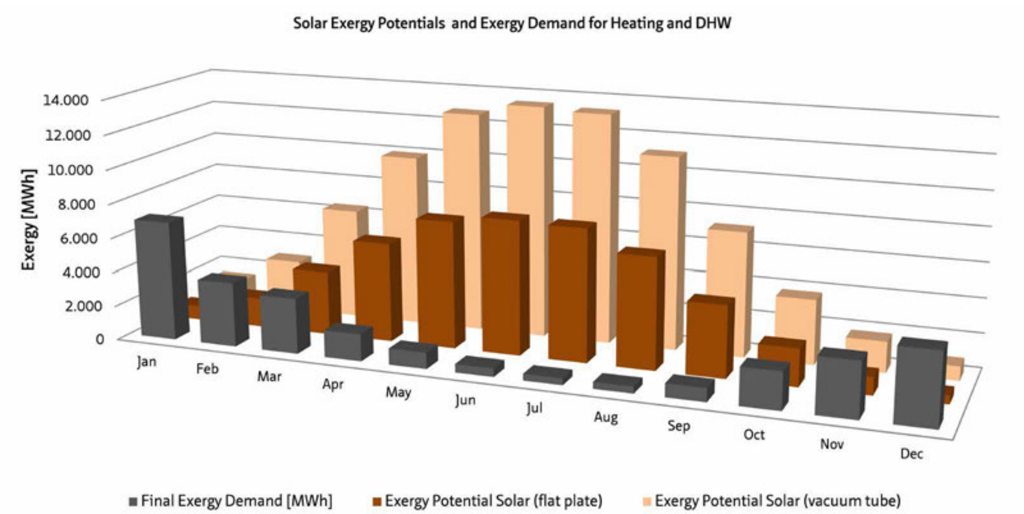

FIGURE 2.13 Communal exergy demand and potentials available from solar radiation on well-oriented residential roofs.

Even under the unrealistic precondition to use all well-oriented roofs for solar exergy production, it is obvious that the yearly potential is immense. On the other hand the disparity of demand and supply over the year become evident. A simplified exergy indicator shows the 'matching' of demand and supply, for instance by the ratio of locally produced exergy for the given demand on a monthly basis. Compared to an annual average this already indicates in good detail the potentials for system improvement. These improvements are based on a two-column strategy: the overall reduction of exergy demand and the substitution of high-exergy supply systems by low-exergy alternatives (Figure 2.14).

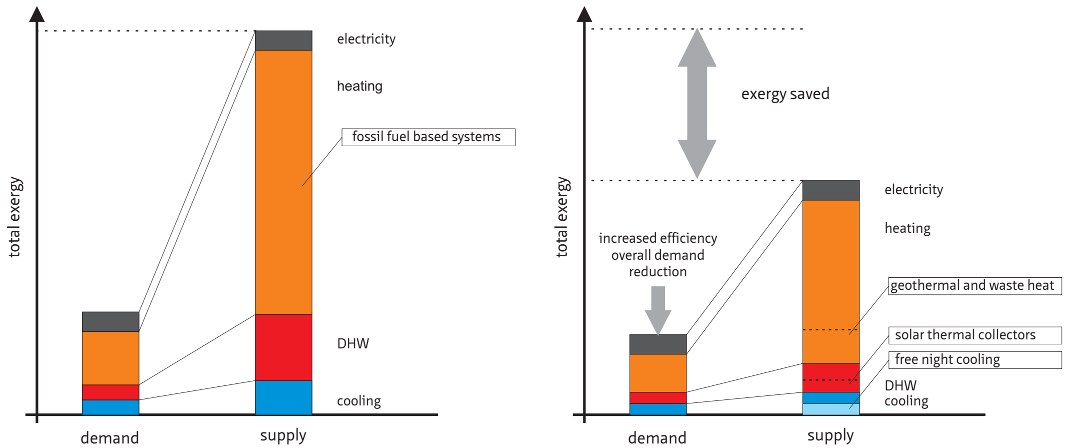

FIGURE 2.14 Improvement of communal exergy efficiency by demand reduction and supplement of high-exergy supply systems.

With regard to the indicator system an increasing parity of local demand and supply structures on an exergy basis can be regarded a positive development for the transition process. The quantity of improvement highly depends on the options and potentials within the community boundaries. An exergy potential map can form the basis for the system analysis on a monthly basis to depict the most promising strategies for improvement measures. From that basis the success values for the development can be defined and monitored on a yearly basis.

Import Dependency

Energy dependency is an aggregated indicator combining both demand side and supply side indicators. Net imports are calculated as total imports minus total exports. Energy dependency may be negative in the case of net exporter communities while positive values over 100 % indicate the accumulation of stocks during the reference year. In the context of increasing energy autonomy the energy dependency will decline gradually. Energy autonomy can be regarded reciprocal to energy dependency. To align with the present global definition of energy dependency in this case energy qualities are neglected. To take into account the more detailed and descriptive exergy evaluation the local energy imports are used.

$$energy\ dependency\ [\,\%] = \frac{\sum net\ energy\ demand}{\sum net\ energy\ imports - \sum net\ energy\ exports} \times 100$$

FIGURE 2.15 Equation 6

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The definition of the rating scale is again dependent on the target and vision. Rural communities might well define their goals as becoming 'net energy independent', meaning that on a yearly basis the export equals the imports. This is a common approach for balancing both plus-energy houses and communities. Usually the balance is limited to household and sometimes industrial electricity. From the technological point of view this is not a satisfying view because it does not lead to holistic development measures but the maximising of renewable electricity production. Taking into account also heating and cooling demands and transportation significant improvements are much more difficult to achieve. To display some quick progression a limited energy dependency indicator might be used for a limited sub-theme as electricity. The decision of supplying the municipality of Wolfhagen with 100 % locally produced electricity by 2020 could for instance be monitored in a first step on the basis of a simplified energy dependency. The next step is of course predictable: either to include other energy carriers into the balance or to achieve a technologically more correct autonomy by increased demand-side management, storage and grid management.

§ 2.5.5 Indicators on specific local aspects

Communities have different preconditions and local influence factors that play an important role in the planning and implementation of energy transition processes. These factors can become very influential to the progress of the measures. The indicator system shall show a great deal of flexibility to set priorities in the target definitions and the pathways to arrive there. The specific local indicators leave room to define specific local aspects important for the development of the energy transition. It is important to give these local specialities room for evaluation and monitoring. This can increase the local identification with the transition process and making it a very specific municipal approach. Aspects are represented that are otherwise lost, if only the common global indicators are used. For the community of Wolfhagen for instance the foundation of a civic energy cooperative is an essential step-stone in the energy transition process. The success of delegating the responsibility and layout of the future energy system to the democratic participation of the inhabitants highly depends on representation and participation. For the development index of Wolfhagen an indicator is necessary that allows monitoring the development of this cooperation. Another indicator takes into account the difficult weighting between interests of natural habitat protection and the extension of renewable energy areas. To avoid the impression that nature is sacrificed for energy interests, both aspects should reflect in the index to show progress in both fields.

It is important to note that developing and displaying the locally relevant indicators draw a 'personal picture' of the communities' ambitions and strategies.

§ 2.6 Conclusions

Based on clear energy visions and target definitions an indicator set can help to show and communicate progress of the transition paths of the community. With a clear pictographic display of the outcomes and developments of the different defined fields of action the communities' stakeholders are enabled to show and monitor progress in a more differentiated manner than when only relying on the well-known economic and demographic indicators. The weighting of the individual aspects does not necessarily have to be proportional. Regarding the relevance of the different indicators in relation to the vision statement, the weighting can be varied. This is as well an issue for communal agreement and consensus. A possible distribution of weighting factors for the city of Wolfhagen is shown in Table 2.10.

GROUP	WEIGHTING	INDICATOR	WEIGHTING
I Communal Development	5 %	population	2.5 %
		demography	2.5 %
	10 %	unemployment	5 %
		debts	5 %
II Global Environment	30 %	CO_2-emissions	10 %
		energy consumption	10 %
		renewable energies	10 %
III Local Energy System	30 %	demand-supply-parity	15 %
		import dependency	15 %
IV Specific Local Aspects	15 %	participation in ESCO	5 %
		natural reserves	5 %
		public transport	5 %

TABLE 2.10 Individual weighting factors for the indicator system

This takes into account that 'energy transition' is the core aim of the initiated process. This justifies the higher relevance of the energy-related aspects compared to the communal development indicators and the specific local aspects, which are given less relevance in this context. The transparency of weighting and evaluation is an important factor for successful communication. Weighting factors and the setting of priorities is a core objective of strategic political planning and should be discussed and decided upon in a moderated political stakeholder participation process. In this case the weighting factors have been defined by me, taking into account the priorities of the energy transition process in the case study.

Taking the individual weighting factors and the monitoring results over the aggregation period, an overall weighting can be derived which shows for instance the development over the past year. Figure 2.16 shows a possible outcome of the defined development indicators for the community of Wolfhagen for the year 2012.

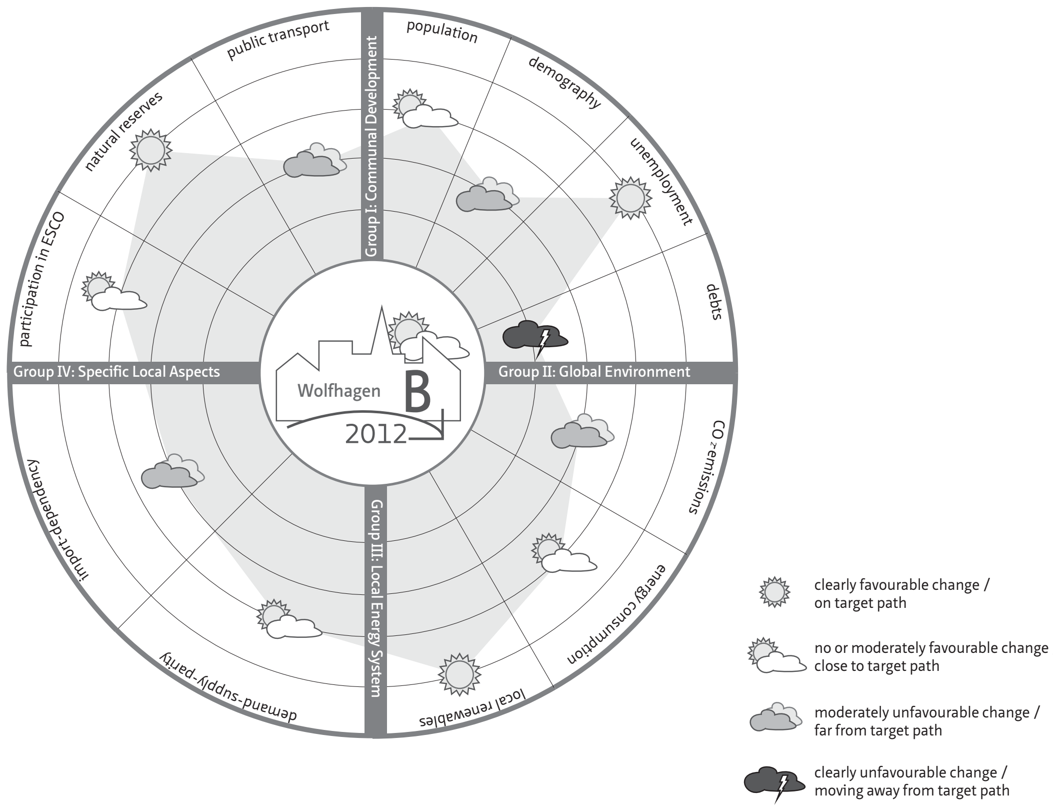

FIGURE 2.16 Total outcome of a graphic display of a yearly monitoring of the indicator set

In contrast to a tabular outcome, clearly the 'problematic' sectors become visible. Although the overall rating might still show a positive development, the community can clearly indicate fields of action for the new monitoring period. The overall rating shows the compliance with the communities' vision statement. On the first glance the communities' 'weather forecast' is easy to communicate: the sunnier the outcome, the closer the community comes to its envisioned transition path. Anything mostly cloudy and stormy indicates that regression has occurred: the development is moving away from the target.

Such an indicator system does not work completely without commenting and some explanatory text. Nevertheless it can form a discussion basis that is much more easily accessible for laymen and the public than other common scientific indicator systems.

On a more detailed level the indicators are of course analysed in a detailed quantitative manner. In a scenario generator the effects of measures in the different sectors can be simulated and analysed. This detailed analysing environment will be object of the proceeding chapters and the main outcome of the research work. As an introductory chapter here the importance of formulating a communal transition vision was described. On the basis of this vision a tailored indicator-set and the target levels and success factors can be defined by the community stakeholders under an active participation of the local inhabitants. It is important to include specific local aspects of special importance to the local situation. The indicator set should not be regarded a rigid inflexible global system but should reflect the special interests and targets of the community. Therefore the global indicators that allow a cross-comparison between different communities are kept to a limited number.

As well the target definition should be individually defined and consented upon. The core imperative of setting up any indicator systems as a monitoring tool is the insight in a useful and meaningful outcome.

From the originally stated research question: "What energy visions support communal decision-makers in defining their transition goals?" a concise concept was developed in this chapter. The principle vision statements will be followed-up in chapter seven, when the energy transition visions for the case study are developed. The evaluation matrix and the indicator sets will be used in the application of the model for the case study in chapter eight. I believe that a rather simplistic display of key parameters helps decision-makers to take strategic decisions. The shown image gives a clear and easy-to-comprehend- overview on the principle development of the community. The next chapters reviews existing tools and models and gives some principle insight into modelling in general since the model will have to integrate the results of this chapter later on.

3 Modelling urban energy systems

"You don't change things by fighting the existing reality,
you change things by building a new model that makes the existing one obsolete."
Buckminster Fuller (1895 – 1983)

§ 3.1 Introduction

To evaluate the impacts of measures and policies or to outline possible scenarios the creation of mathematical models and simulation environments is a well-established and practiced scientific method. The modelling of complex system behaviour is not a new aim. Urban energy systems, other than for example urban transportation or industry location, however, have come in focus of modelling not so very long ago. The newly perceived global threats of anthropogenic environmental impacts led to the first attempts to model the possible future effects of human energy consumption on the global climate system back in the 1970's, published for example in The Limits to Growth by Donella and Dennis Meadows *et al.* (1972), and later, as World3 model (Meadows *et al.* 2004). From that moment on both modelling know-how and computer technology underwent fast developments and allowed models to become more dynamic and to cover more complex issues and address broader questions. With the starting 21st century energy is again a dominating issue on the political agenda. The limitation of fossil energy sources is a commonly accepted reality, regardless from the exact occurrence of 'peak-oil'. There is no doubt about the uprising importance of renewable energy carriers for a sustainable future development alongside with a necessary significant increase of efficient transformation and severely reduced demand. Renewable energy production in most cases also means decentralised energy production. This consequently moves the focus towards local, urban or regional solutions. Under the precondition of a fast and targeted energy transition on local and communal level, a different target group of decision-makers and local stakeholders also come into focus for modelling tools. Global climate models as well as simulation tools for most detailed scientific questions were never meant to be applied by local politicians and planners. To provide them with useful information and modelling tools with regard to their specific local conditions is a fairly new task for the scientific community of model builders. Having thrived mostly for more precise and predictive outcomes in ever more complex model architectures, the existing approaches demand for expert users. Nevertheless, some attempts and developments have been published to address the needs of every day work on a local level.

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This chapter will give an overview on older and recently published tools and methods in the broad field of energy systems modelling with a specific target to communal application. The chapter is structured according to the questions asked to the model environment similar to the considerations made in chapter two. This is important because a model always only represents a subset of all factors which influence the system behaviour in reality. Both the model's architecture and outcome will be strongly determined by the model's purpose and questions asked. The literature review is focussed on models addressing the relationship between communal demand and supply structures and issues of sustainable energy transition. The compilation of existing approaches remains incomplete and exemplary. This is due to the fact that over the past years the number of different modelling approaches in the energy field has risen exponentially. The overview is meant to create insight into the modelling fundamentals and to create a knowledge base to continue the developments of the model in the modelling and processing section.

§ 3.2 Methodology

The chapter is structured according to the present differentiation of existing energy models, starting with a principle outline of characteristics that can describe energy models. The terms tools, methods and models are often used interchangeably. A model in this chapter is referred to as a mathematical description of a real process or system. Within the model an intrinsic method of problem solving or evaluation is implemented, for instance optimisation algorithms in simulation models or econometric methods within a backcasting model. Therefore the methods tell much about the models' purpose. Tools implement models and usually provide user interfaces for input parameters and evaluation. Therefore the mathematical core of the models is often not accessible in the tools. In the following the principal differentiations between methods and tools for energy systems modelling are outlined and described. In this chapter a model is considered to be the "structural background" of every tool. The model resembles the "philosophy" or principle idea of what is to be described and how the questions are to be answered. Therefore models are core elements of tools, which can contain and combine different models. The review of different model characteristics therefore gives an overview of the principle options and targets different models can address.

There is a multiplicity of available tools used in the context of energy system modelling and the development of new tools is dynamic. The chapter describes some of the tools that represent certain typical aspects and states of modelling approaches. For this, literature and tools were reviewed. There are a few comparative publications on energy system tools available (Grubb *et al*. 1993, Hourcade *et al*. 1996, Beeck 1999). These were used as a basis for further research on new developments and scientific publications. The review on more recent applications and developments of energy models was limited mostly to publications focussing on German and Dutch locations because the case study is located in this context and the planning framework and challenges are comparable (Kragt *et al*. 2003). In this context the PhD thesis of Richter (2004), Beeck op. (2003) and Biberacher (2007) are of interest, because they aim at a holistic representation of the energy systems. To go a step beyond approaches of dynamic system modelling were evaluated which have not yet found their way into energy system modelling. Albeverio *et al*. (2008) give a profound overview on the status quo in this scientific field and Bossel (2004) gives an introduction on how to approach practical modelling. In order to reach the goals for a sustainable transformation of urban energy systems and give political decision-makers useful support future developments have to use the available knowledge to avoid "reinventions of the wheel" and to achieve a broader applicability and user-oriented transparency. Options and ideas for this will close this chapter.

§ 3.3 Energy transition in communities

Energy issues rank high on political agendas in many Western European communities. Consequences of climate change become increasingly obvious. Prolonged hot summer periods, unprecedented rainfalls and floods raise awareness for possible situations still to come. The supply dependencies on politically instable regions make society vulnerable. With general climatologic consent on the causality of human activity on climate change (IPCC 2007), scientific groups all over the world have tried to model future developments of these impacts, in order to gain insight into the consequences and impairments of developments and how these could be altered. From an urban perspective, many fields of interest in urban planning have been modelled, for instance urban developments and sprawl, distribution of inhabitants and industry. In many cases, questions of appropriate infrastructure for sustainable city development and solutions for transportation and traffic problems were addressed within these models. This chapter gives an overview on some principle issues of modelling energy systems and gives examples of recently published modelling approaches from projects and literature. As an overview the following topics are of key interest:

– Boundary conditions for using modelling tools in communal transition projects
– Principle characteristics of energy models
– Examples of energy models and approaches

§ 3.3.1 Goals of urban energy transition

Even though the political and scientific arenas have discussed the core problem of resource depletion for several decades, most middle and small sized communities seemed fairly unconcerned with energy issues so far. This may result from the fact that energy supply has not been a core competence and responsibility of communities and city administrations. Energy supply was either the business of associated communal utilities or externalised to the “big players” of interregional or even international energy supply. Communities themselves were mostly in the role of being consumers rather than producers and distributers of energy. The growing market and opportunities for renewable energy production, as well as promises of investment profits and the promotion of local economic development, have recently motivated many communities to take a more active role in the energy field although this may be outside of their core business and competence.

The future prognosis of this shift to local energy entrepreneurship is promising (Hirschl *et al.* 2010). Increased independency from external energy suppliers offers communities freedom of setting priorities in energy issues. Locally available resources can be integrated in the communal system, regardless of the investment interests of the large energy companies. The investment decisions are based on local interests and priorities rather than inter-national company policies. The local fade-out of nuclear and fossil energy returns democratic sovereignty to local actors. The power of this regained independency has been shown by several German and Austrian communities, such as Jühnde, Schönau or Güssing. Hirschl *et al.* (2010) illustrated the economic potentials and opportunities of renewable energies (RE) for communities. For a medium-sized model community of 75,000 inhabitants with renewable energy technologies at national average the study calculates a local added value of € 3 million, avoided costs for fossil fuels of the same amount, avoided CO_2-emissions of 55,000 tons per year and 50 new full-time positions in RE service companies. This emphasises not only the environmental but also economic dimension of energy transition.

§ 3.3.2 Urban planning and modelling tools

Being laymen in most fields of energy demand and supply, communal stakeholders and decision-makers find themselves facing new and challenging tasks such as decisions on local wind energy premises, building permits for solar energy plants on inner city roofs or efficiency campaigns for communal and private buildings. The responsibility for both urban and local rural development means that core fields of interest in the energy domain fall under their supervision and planning sovereignty. This also means

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that communities can no longer ignore energy-related questions to planning and city development. Models and scenario tools promise overview and science-based decision support.

Nevertheless, there are also critiques to the use of modelling tools in urban and regional planning processes. Modelling can be a powerful tool in the necessary information and communication tasks needed in all planning processes. Roggendorf *et al.* (2011) state that the low spread of complex models has several reasons in the current planning practice. Beside the high implementation efforts and data situation, the authors state a common scepticism among planners against quantitative prognosis tools. This leads to the current situation of only little collaborative development work between planning practice and scientific model development (Briassoulis 2008). The critiques from the planners mostly address the complexity of the models and the often intransparent calculations and theories behind them (Koomen & Stillwell 2007). A principle problem is the mathematical and technical approaches of the modelling architectures and the planning processes, which often are hardly formalised and sometimes unstructured (Te Brömmelstroet 2007). A closer cooperation and targeted cooperation between scientific modellers and urban and regional planners can be regarded a "must" if the full potential of modern technologies, be it GIS-data infrastructures or complex systems analysis, is to be exploited for energy transition processes on urban scales.

For the practical application of modelling technology Roggendorf *et al.* (2011) give a dictum of six important aspects to consider:

1 **Problem first** – The initial task should be the definition of the problem to be solved and the statement of a problem hypothesis. This is important because planners, and sometimes scientists as well, tend to quickly concentrate on the application of a certain method instead of a clear problem description.

2 **Task definition** – Methods as well as tools should fit to the problems to be solved. Routine tasks demand different procedures than specific and complex issues, which might have only a justification for a limited time and scope.

3 **Risk consideration** – All decisions in urban and regional planning are taken under certain risks. By applying appropriate methods, such as sensitivity analysis, the consequences, opportunities, probabilities and risks should be systematically evaluated.

4 **Do not forget anything important** – To ensure that no important aspects are forgotten the decision making process should undergo several runs. Applied methods should be targeted at changes in perspective towards the problem such as a meta-perspective, a conceptual perspective and a detailed perspective.

5 **Reduction of time and effort** – The efficiency directive applies also to methods: more data should not be collected without a defined decision problem. The results have to be in a good proportion to the effort put into them.

6 **Reduction of complexity** – The total number of options should be reduced step by step, starting with the most unrealistic. Fast and simple methods should have priority over complicated experts' tools.

Good and efficient problem solving demands tools that match these aspects and can be applied by the involved planners. The transition of urban energy systems will never be a simple task and not one single tool will answer all questions entirely. Personal preferences and procedural traditions will always have a major influence on the use of tools and methods.

§ 3.4 Tools for Urban Energy Modelling

§ 3.4.1 Principle Characteristics of Energy Models

With increasing possibilities of applying computer-based methods to planning, the number of mathematical models on energy systems has increased tremendously. Common to all modelling is the fact that any model represents a simplification of the real system, covering only the aspects of interest or specific targets questioned. The starting-point of any new modelling project should be the identification of the most appropriate available tool or method. The multiplicity of available tools and approaches asks for some simple classification and decision support. Hourcade *et al.* (1996) distinguished energy models by three main characteristics: their *purpose*, their *structure* and their *external or input assumptions*. While the purpose of the model is crucial to the initial architecture of the model and the interpretation of the outcomes, the structure mainly determines the qualitative outcomes of the modelling in terms of incorporated parameters and the level of detail that can be derived from the model results. Another systematic analysis was done by Beeck (1999), who characterised energy models according to nine characteristics. Table 3.1 gives an overview on the different levels of characteristics energy models can be differentiated by.

CRITERIA	SUB-CRITERIA	CHARACTERISTICS
Ia – General Purposes	Ø Forecasting	Short term prediction of developments, based on known historic behaviour
	Ø Backcasting	Development of visions towards desired future state
	Ø Scenario Analysis	Comparison of different scenario options compared to a “business-as-usual” base-case
Ib – Specific Purposes	Ø Energy Demand Analysis	Focus on the development of energy demand structures due to population, income, energy prices
	Ø Energy Supply Analysis	Focus on energy supply technologies to meet given demands
	Ø Impact Analysis	Focus on the effects of changes to model parameters such as policies, financial/economic conditions etc.
	Ø Appraisal Analysis	Focus on the evaluation of different options regarding certain indicators such as costs, efficiency
II – Model Structure	Ø Degree of implemented parameters	Degree of internal parameters within the model. The higher the degree of internal parameters the more deterministic the model behaves (simulation models).
	Ø extent of non-energy parameters included	Degree of non-energy aspects included. Suitable for analysing the effects of policy measures on the entire economy.
	Ø extent of description of energy end-use	The more detailed end-use characteristics are implemented the better efficiency measures can be evaluated.
	Ø extent of description of energy supply technology	Detailed description allows the analysis of different technology alternatives. Often not included in economic models.
III – Analytic Approach	Ø Top-Down	“pessimistic economic paradigm” Mostly in economic models without detailed representation of energy supply systems.
	Ø Bottom-Up	“optimistic engineering paradigm” aiming for best solutions reflecting technical options and underestimating non-technical influences.

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CRITERIA	SUB-CRITERIA	CHARACTERISTICS
IV - Methodology	Ø Econometric "trend analysis"	Statistical methods are used to extrapolate historic developments into the future and forecast future developments
	Ø Macro-economic	Multi-sectoral effects and transactions between economic sectors for exploring purposes
	Ø Economic Equilibrium Models "resource allocation models"	Used to study energy sector as a part of the overall economy on a long-term scale under optimal market equilibrium conditions.
	Ø Optimization	Often used for identification of optimal investment strategies. Outcome represents best result under given constraints.
	Ø Simulation	Static or dynamic simulation is used instead of experimental scenario analysis. Highly deterministic and usually complex.
	Ø Spreadsheet Models (Tool Boxes)	Often referred to as modular model-packages with reference cases which can be modified according to local requirements.
	Ø Backcasting Models	Used to construct visions of future energy scenarios and pathways for their realisation. Often using interviews of stakeholders and experts.
	Ø Multi-criteria Models	Implements other than economic, quantitative as well as qualitative aspects into the modelling.
V – Mathematical Approach	Ø Linear Programming (LP)	Rather simple mathematical approach for all problems which can be described by linear equations. Used for optimization models.
	Ø Mixed Integer Programming (MIP)	A mixed-integer program is the minimization or maximization of a linear function subject to linear constraints. Mixed integer programs can be used to formulate just about any discrete optimization problem.
	Ø Dynamic Programming	Dynamic programming used to solve complex problems by dividing them into sub-problems which interconnections are defined and combine to the greater problem solution.
	Ø Multi-criteria Decision Aid (MCDA)	Methods for analysis of complex decision problems involving immeasurable, conflicting criteria. MCDA problems involve a set of alternatives that are evaluated on the basis of conflicting and incompatible criteria.
	Ø Fuzzy Logic	Fuzzy Logic can be used for modelling vague and undefined expressions often found in subjective evaluations and assumptions with a high degree of freedom in operators.

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CRITERIA	SUB-CRITERIA	CHARACTERISTICS
VI – Geographical Coverage	Ø Global / International Ø National	Mostly focussed on top-down, multi-sectoral, econometric or overall economic equilibrium models demanding highly aggregated data.
	Ø Regional Ø Local	Mostly bottom-up approaches and more focussed on technological solutions for specific conditions.
	Ø Project	Somewhat special scope with very focussed and limited target and dimension.
VII – Sectoral Coverage	Ø Single sectoral	Models covering only one sector as early bottom-up models.
	Ø Multi sectoral	Covering more than one sector of economy e.g. according to the International Standard Industrial Classification (ISIC).
VIII – Time Horizon	Ø Short Term Ø Medium Term Ø Long-term	There is no standard definition of short, medium and long-term modelling. The time horizon is to some extent dependent on the models' purposes and covered sectors. Commonly in energy systems short term could be regarded as < 5-10 years, medium term 10-20 years and long-term of more than 20 and up to 50 years.
IX – Data Requirements	Ø Qualitative Ø Quantitative Ø Monetary Ø Aggregated Ø Disaggregated	Different model configurations demand different sets of data at different aggregation levels. Requires data in top-down models is a lot more aggregated than the disaggregated data needed in most bottom-up models. The availability of data is sometime the essential crux and bottleneck for applying models successfully.

TABLE 3.1 Characteristics of energy models (Grubb *et al.* 1993, Hourcade *et al.* 1996, Beeck 1999)

The differentiation between different model architectures is not clearly distinct by this set of criteria. Theoretically there may be as many existing models as there are questions to energy systems.

§ 3.4.2 Large-Scale Models and Tools

A list of available tools for energy systems analysis is given by the World Bank's "Tools for Assessment: Models and Databases". The three stated energy system models EFOM-ENV, MARKAL and MESSAGE-III are bottom-up models for building scenarios and optimisation based on linear programming. The scope is mostly on national or even global scale. All three models have undergone some evolution from their basic origins and have been applied in several studies, (e.g. Spitz 2009, Broek *et al.* 1992, Seebregts *et al.* 1999. Because of their complexity and mathematical architecture their scope is limited to scientific application.

Toolbox-models or modular packages such as ENPEP[22], LEAP[23] or MESAP[24] consist of different kinds of models such as macro-economic components, and energy supply and demand balance models which are integrated into a package. The user does not need to run all the models but may select only a subset depending upon the nature of the analysis to be carried out. The tool e-TRANSPORT[25] is a similar toolbox for energy system analysis and optimisation. The set-up of the modelling environment is quite complex for all these tools and usually offered as service by the developers. The results are displayed in tables, graphs and charts.

For a further analysis of approaches and tools the perspective is limited to tools focusing more on local applica-tion. Keeping in mind the aim of enabling local decision-makers and planners to find solutions for a transition of fossil fuel based energy supply towards renewable and highly efficient energy structures, the focus is

22 ENPEP "Energy and Power Evaluation Program" was developed at the Center for Energy, Environmental and Economic Systems Analysis (CEEESA), University of Chicago, Argonne, IL, USA

23 LEAP "Long range Energy Alternatives Planning System" was developed at the Stockholm Environment Institute (SEI), Stockholm, Sweden

24 MESAP "Modular Energy-System Analysis and Planning Environment" was developed by the Institute for Energy Economics and the Rational Use of Energy (IER) at the University of Stuttgart in 1997 and is now commercially maintained by the company Seven2one Informationssysteme GmbH, Karlsruhe, Germany

25 eTRANSPORT is an energy infrastructure planning tool developed at SINTEF Energy Research Department, Trondheim, Norway

laid upon the local and regional scale which is influenced by local policy and planning. The appropriate time-scale is most probably medium- to long-term since transition processes take more than a couple years. Furthermore multiple sectors have to be covered. The energy supply sector is represented by energy companies, utilities and the market of fuels. The sector of energy demand includes the building stock, the user behaviour and the different construction industries. Political influences, be it on an intrinsic local level or an endogenous external level, plays an important role as well. Therefore, quantitative as well as qualitative aspects are of interest. Leaving open the question of methodology and mathematical approach it seems clear that there's only a subset of models addressing these issues.

§ 3.4.3 Energy demand and potential analysis

The analysis of energy potentials and demands is a modelling approach with a rather limited perspective in most cases. The focus is usually one sector, e.g. the solar energy potentials as discussed by Everding & Kloos (2007), or a sum of renewable energy sources for electricity production as in Klärle *et al.* (2011). The aim of the associated tools and guidebooks mostly address local decision-makers and intend to support their initiatives for the utilisation of renewable energy sources.

Solar potential cadastres

The potential analysis is commonly transferred to web-based tools facilitating the local reference and, in the case of solar cadastres, offering publically available features such as economic evaluations of solar technologies (PV or solar thermal), investment costs and payback times. This, mostly focused on the use of photovoltaic cells, because here the information is less dependent on user and building structures (Figure 3.1). These types of solar potential cadastres have become quite popular in Germany, although frequently problems of data security and the options for public and potentially commercial use of the data have been intensely discussed and there are different views on the rating of building-related geographical data (Weichert 2007).

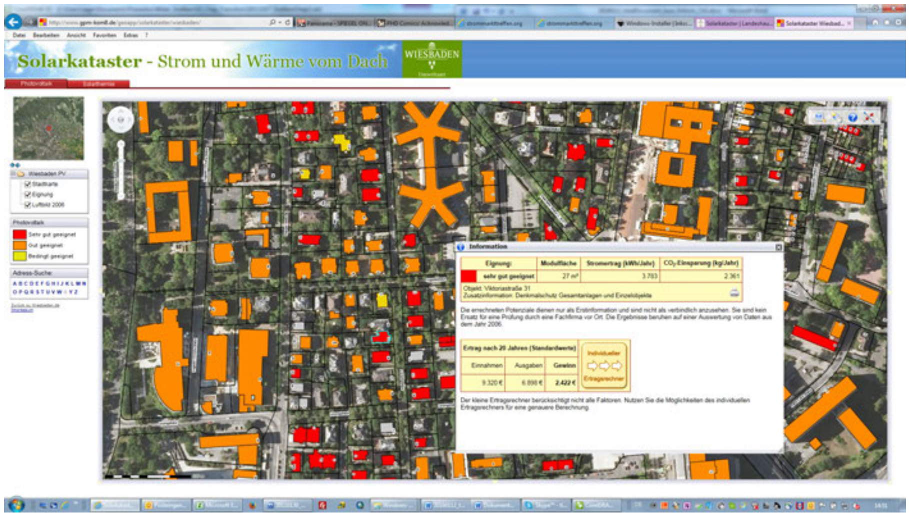

FIGURE 3.1 The solar cadaster of the city of Wiesbaden offers a profit calculator based on the roof areas

Energy Potential Mapping (EPM)

The concept of Energy Potential Mapping (EPM) was developed after the Grounds for Change Project (Roggema et al. 2006), which had to find new energy perspectives for the Northern Netherlands. In enhanced versions, EPM was applied to several projects on local and regional scale in the following (e.g. Dobbelsteen et al. 2007, Dobbelsteen et al. 2008, Broersma et al. 2009). The objective of Energy Potential Mapping is to support the deployment of locally available renewable energy sources such as sun, wind, geothermal heat and biomass to supply a present or future energy demand of a specific area. In addition a number of anthropogenic energy sources such as waste heat from farming or industrial production and solid or fluid wastes can serve as local energy sources. The areas studied may vary from buildings and their direct surroundings, via neighbourhoods and cities up to entire national regions. Dobbelsteen et al. (2011) and, later Broersma et al. (2013) describe the potentials of the methodology in the demand for visualising the locally available energy sources as a planning basis for optimised energy supply infrastructures. The EPM collects data on all essential characteristics of an area (climate, land use, underground, etc.), translates them to available energy sources and maps them. The potentials are displayed in different layers (Figure 3.2) to give decision-makers and planners an idea of possible development outlines in an optimised manner in terms of energy.

The spatial distribution of energy demand and potential structures takes into account that low valued (low-exergy) renewable energy sources, such as low-temperature heat, are to a strong degree locally bound and cannot be transported over long distances in

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an efficient way. This is also true for local heat and cold storage potentials. The mere accounting of energy quantities in a regarded district does not reflect the limits to distribution that are inextricably connected to most renewable and waste energy sources.

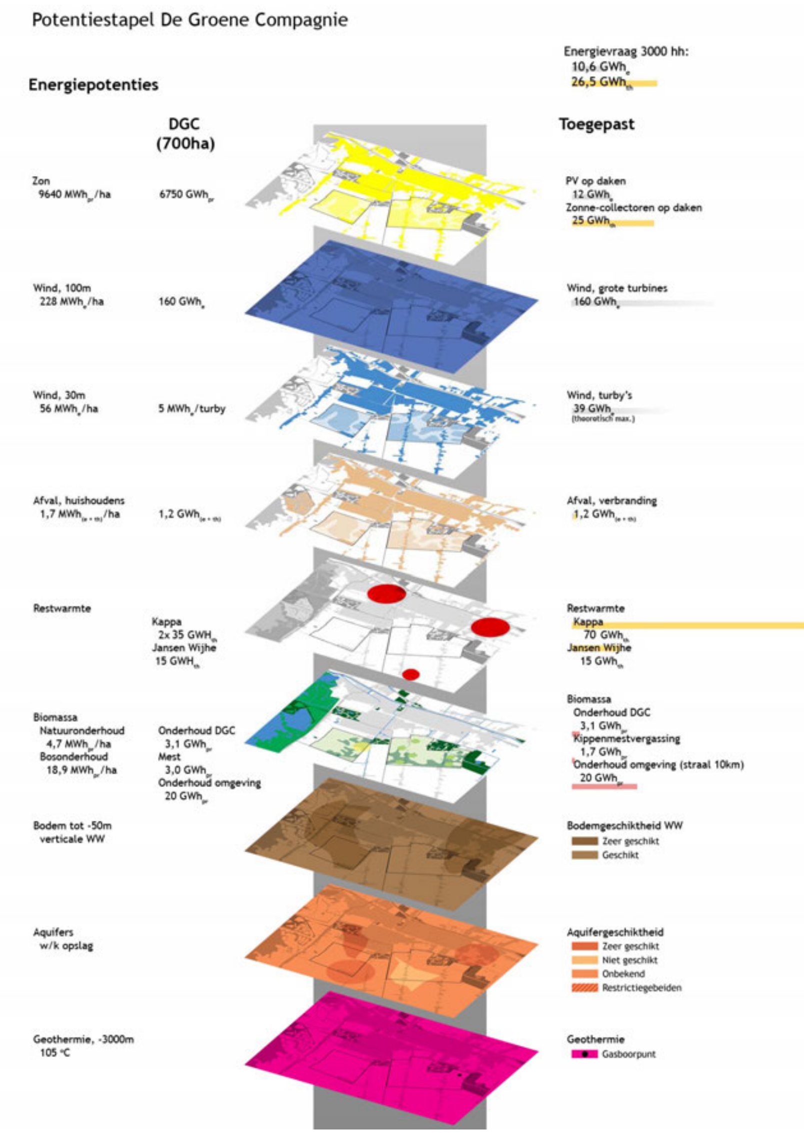

FIGURE 3.2 The stacked energy potential pile of 'De Groene Compagnie' in Hoogezand (Broersma *et al.* 2009)

On the basis of the EPM method a national heat map for the Netherlands was developed (Broersma *et al*. 2010). For the first time in the Netherlands heat potentials and demands were displayed in a three-dimensional way on national level. Both natural and local anthropogenic sources were displayed as geometrical volumes, reliefs and piles. On a zoom-level the matching of positive (potential) and negative (demand) piles visualise the locally achievable utilisation of existing potentials (Figure 3.3). In comparison to the larger regional EPM the heat map potentials are already rated by their technical usability and set up in a comparable one unit scale (GJ).

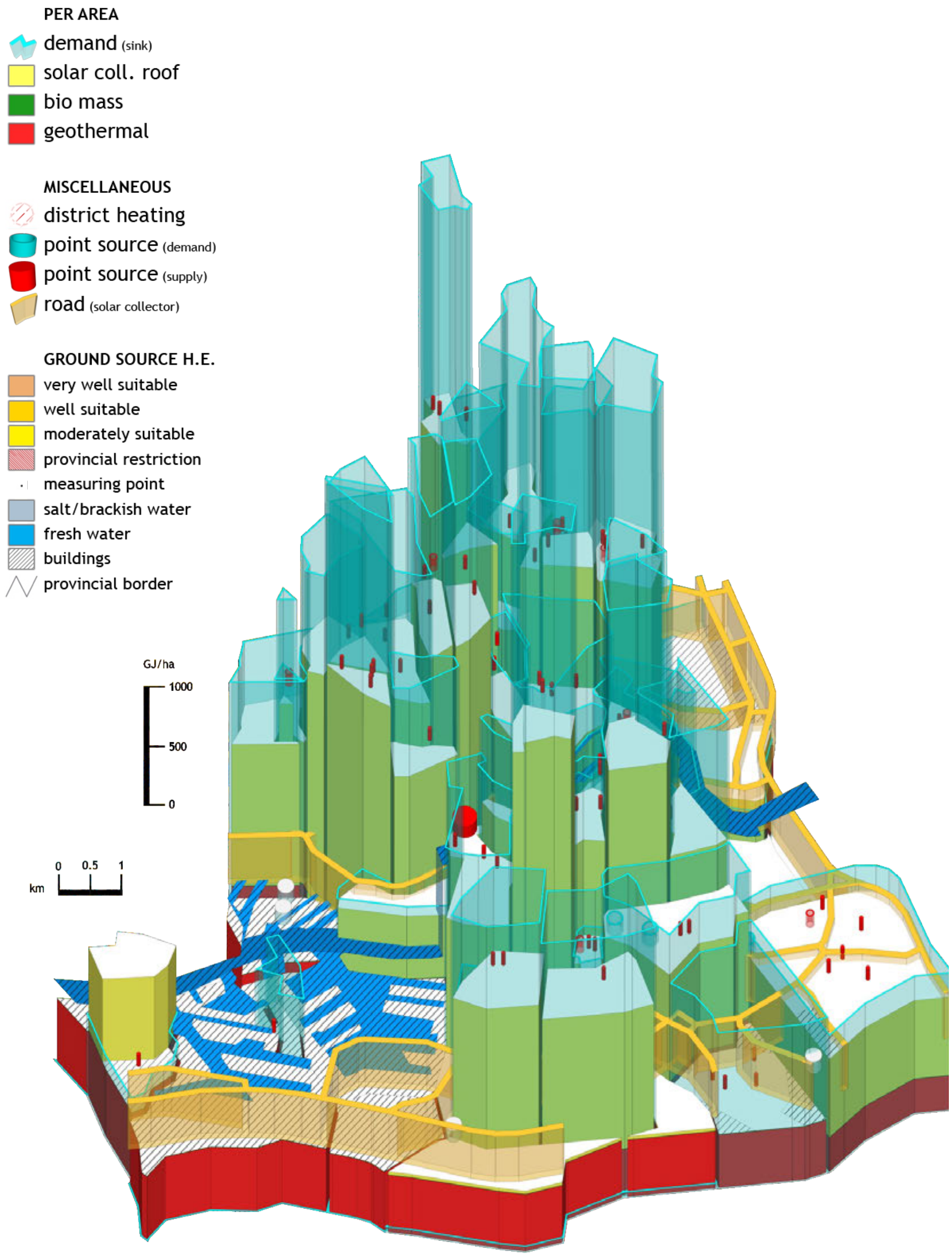

FIGURE 3.3 Detailed heat map of the central district of the city of Rotterdam: hollow cores indicate heat demands, full cores and layers are heat potentials, natural and anthropogenic (Broersma *et al.* 2010)

§ 3.4.4 Demand and Supply Systems in "Steady-State"

Traditionally urban planning approaches aim at transferring city structures from one equilibrium state to another. All urban development programs are centred at the transformation of the current status quo of buildings and / or functions of districts, cities or regions. The understanding of city systems in planning has traditionally been based on this approach to take the behaviour of the interactions between the involved components as deterministic agents in an equilibrium state. The description of energy systems on district or city scale in a first attempt always aims at the identification of the demand and the supply structures within the geographical extend of the system boundaries. This is a reductionist approach assuming a steady-state situation for the demand and supply structures for a number of time steps. The greater the number of time-steps gets, the more a "quasi-steady state" behaviour is assumed. In his doctoral thesis Richter (2004) developed a modular tool called Urban Research Toolbox: Energy Systems, which is based on the description of the late developments of a city, represented by a set of indicators and projecting this development into the future. It is therefore a typical forecasting model with a high degree of deterministic behaviour. Richter states the number of residents, the living space per inhabitant, the heating energy demand of the living space (given by the building structure), the economic development (given by the gross domestic product GDP and the number of employees) and the electricity demand per inhabitant and economic output as key endogenous indicators for the mathematical description of the energy system. A set of four sub-modules structures the tool into urban development, energy demand, energy technology and environment issues. The mathematical and technological approach neglects mostly the factor and roles of human actors and stakeholders and therefore has to neglect the human influence on the scenarios. The optimisation process is therefore dependent on the technological base-line in the reference scenario and the projection of the indicators. Taking one step at a time the changes within the system are based on the same steady-state equations. The outcome of scenarios therefore must follow the initial directive of parameters in a more or less linear sequence and logic (Figure 3.4).

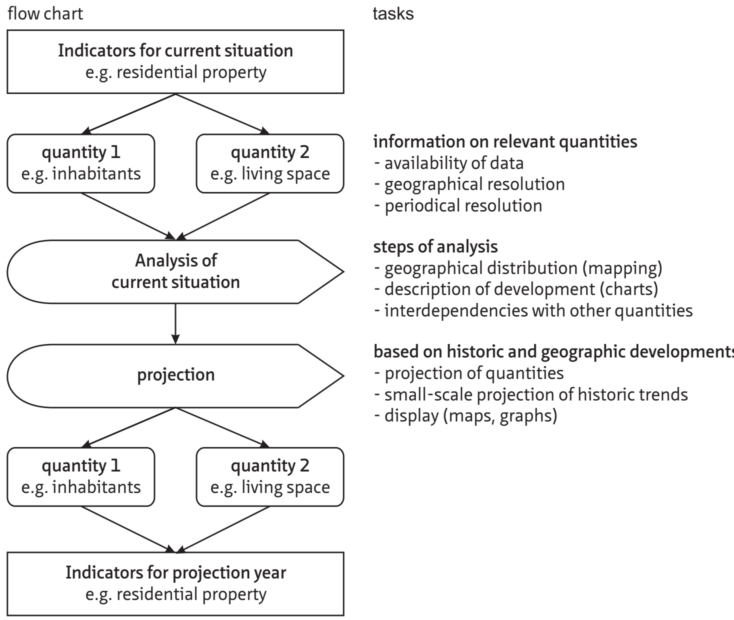

FIGURE 3.4 Example of a flow chart using a step-by-step projection of indicators over time (according to Richter 2004)

The deterministic model of Richter shows some principle short-comings with regard to its predictiveness. Even when taking only the technical parameters of urban energy systems, energy demand and supply structures are highly dynamic, change their central characteristics from season to season and even hour by hour and have strong interdependencies with the specific user behaviour. Energy systems by nature can be characterised by flow processes. These demand necessarily the dimension of time and cannot be described without taking into account the interaction of human factors.

The question to what extent the technical options for the optimisation of the energy system can be realised is raised in Erhorn-Kluttig (2011) placing the interests of the affected actors in the centre of attention. The differences in economical, ecological and political interests often anticipate an objective and to-the-purpose view on alternatives. Because of the complexity of the systems and the interdependencies of measures the demand for new instruments and tools is stressed. The task of energy system optimisation is regarded an iterative process with the different targets and goals of the participating interest groups being important influence factors for the measures and system characteristics (Figure 3.5). The tool developed in the German research initiative Eneff:Stadt aims at the needs of urban planners and local political decision-makers and appears to follow a qualitative backcasting design. The tool is supposed to offer a simple to use support on energy options for districts without the need of too much detail information. It is meant for the assessment of potentials of different building related strategies and options for central or local supply systems.

In contrast to the mathematical projection in the work of Richter the Eneff:Stadt tool provides scenarios on the status quo and options to take from there. There is no prognosis implemented for the future development of the energy system. The tool is therefore highly descriptive based on the specific characteristics of the local situation and the technical parameters of the supply systems in a spreadsheet methodology. The algorithms and assumptions of the tool are based on mechanical equations of the technical systems with their economic characteristics without integrating the decision making processes of the involved stakeholders and affected population.

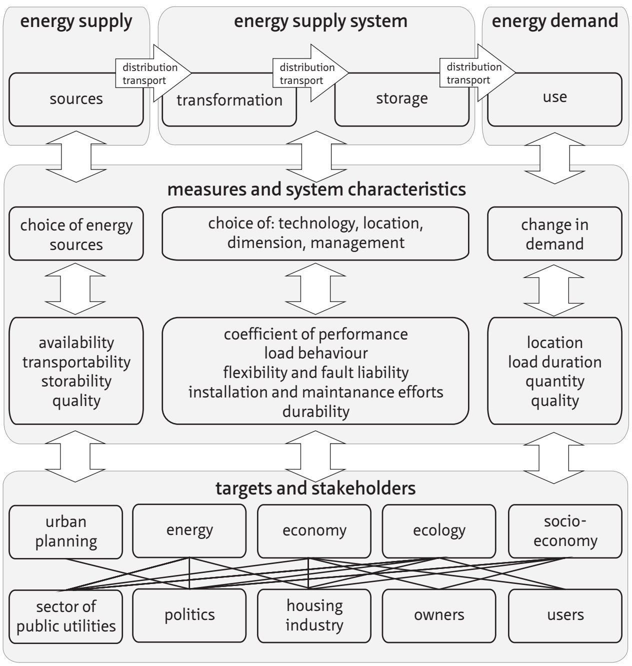

FIGURE 3.5 Scheme of energy system optimisation (according to Erhorn-Kluttig 2011)

§ 3.4.5 Energy Models with geographic reference

In his doctoral thesis Biberacher (2007) developed an energy model with spatial reference. The TASES "Time and Space Resolved Energy Simulation" bases on the work done for the MARKAL and EFOM models and was incorporated in the VLEEM-project funded by the European Commission in 2000-2003. The TIMES development pursues the goals of merging the advantages of existing energy models like MARKAL and EFOM and giving them some surplus value. The modelling idea bases on a backcasting approach, deriving from the large-scale and very long-term research done in the scope of the VLEEM project. TASES calculates all energy flows in a given scenario surrounding and aims at the optimisation of flow and storage patterns. Next to the linear equation matrix which is produced by the program, TASES also includes some evolutionary processes as a novel idea to the energy systems model. The evolutionary optimisation algorithms are used to find better solutions for supply patterns decoupled from the linear program architecture. This means a simplification of finding numerous alternative solutions without running the underlying complex simulation environment. The process is to define a set of feasible solutions which are rated with regard to a defined criterion. The selected alternatives that comply with the criterion are selected, duplicated and varied, or mutated in the biological term. Afterwards the process is run again for a defined number of iterations (Figure 3.6).

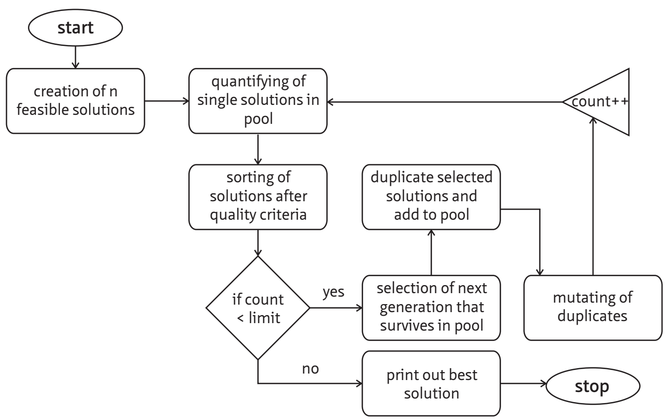

FIGURE 3.6 Flowchart of an evolutionary optimiser based on the principles of selection and mutation (from Biberacher 2007)

The model is primarily developed for the optimisation of energy supply systems including a large amount of renewable energy sources and storage capacities. All optimisation is run against a given and pre-defined demand load duration curve, which is taken irrevocable. The results and the modelling are implemented in a GIS-environment, which allows the inclusion of spatial information to the simulation. This makes the program specifically interesting for all grid and net-related questions, such as the optimization of renewable coverage for a given demand (Figure 3.7).

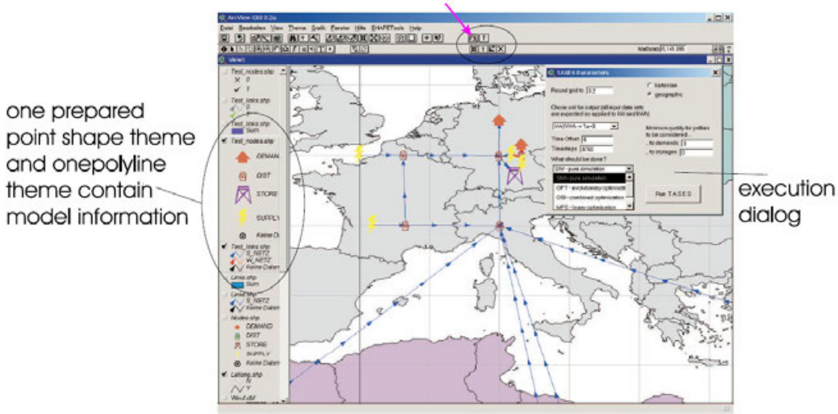

FIGURE 3.7 GIS-based user interface of TASES to include spatial reference to the simulation (from Biberacher 2007)

The model is not focusing on improvements on the demand side. The author is stating a declining demand as not realistic scenario for future developments of the energy demand. The target of the program is mostly the optimization of a renewable electricity supply on a rather large-scale on national or international level.

§ 3.4.6 Dynamic Models of Urban Energy Systems

All of the described approaches entail the limit of being focused on deterministic causalities dominated by technological feasibility rather than the behaviour and options of the involved human actors. This is very plausible from the fact that we can very well foresee the energy behaviour of technical supply system under given boundary conditions and a defined number of iterations and time steps. The question on how people take individual decision for or against energy-efficiency measures is for example far more complex and less deterministic and the research on these issues is still at the very beginning. The central barrier for modelling urban energy systems as dynamic systems is the complexity found within them. In their article Complexity: the Integrating Framework for Models of Urban and Regional Systems Peter Allen, Mark Strathern and James Baldwin formulate the demand of understanding needed "This really means that we need to understand the options that they [the agents and entities involved] perceive, and the trade-offs that their value systems cause them to make, and through this to know how they will react to some policy, action or investment that is contemplated." (Allen *et al.* 2008). The target of trying to build dynamic non-deterministic models of urban processes is not so much to give a precise prediction of most-accurate indicator figures but to rather show up a possible variation of possible scenarios and "relative effects" of the described correlations (ibid.).

A multi-agent approach and the implementation of non-deterministic human behaviour have not yet been applied to urban energy systems. In the scope of urban systems Claes Andersson gives a sceptical view on the power of highly descriptive intrinsic model results. “Indeed, it is obvious that we cannot understand why a city looks the way it does, produces what it does or is situated where it is without a reference to its history. Consequently, urban growth models today are invariantly evolutionary in the sense that there is little concern for notions such as optimality, rationality and equilibrium. [...] Congestion, fragmentation of biotopes and farmland, pollution and so on are definitely features that are neither designed nor subject to diminishing by selection to any important extent.” (Andersson 2008).

It seems plausible that this also applies to the numerous actors and the current situation in urban energy systems from a demand-supply side perspective. Especially the energy consumption side with all the aggregated difficulties of obvious bounded rational decision making and the limits of increasing the efficiency in the existing building stock despite all energy and economic optimisation arguments, seems to show these symptoms. The conclusion Andersson draws is, to carefully analyse the hierarchy of questions being asked to dynamic complex models to not go astray in detail, since detailed results might base on deficient assumptions. Nevertheless the attempt to describe complex systems in their quantitative unpredictiveness may show more insight in how systems behave and how they evolve (Figure 3.8). This way modelling becomes more a “gaming” approach rather than a technological foresight.

Bossel (2004) states that the mere definition and building of a complex system model environment offers much insight and understanding of the system’s behaviour. Attempts to explain the sometimes surprising system behaviour gives room for the identification of possible keys to system change and to identify behavioural alternatives.

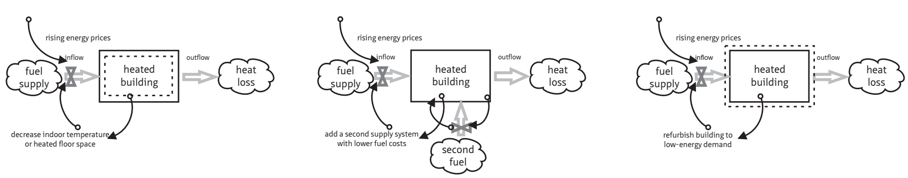

FIGURE 3.8 Behavioural alternatives to react to rising energy prices, which will all have very different effects on the meta-system behaviour (Sager 2010)

§ 3.5 Conclusions

The models and tools described represent a broad understanding of urban energy systems. The origin of most of the tools is in academia and has only little impact on urban planning so far. More simple and focused tools like solar potential cadastres nevertheless have received a great acceptance among communities. The specific area reference and the clear target and usefulness for the local population are most probably important success factors. A closer collaboration between scientists and practitioners in the future may start from this basis.

The development of models for complex urban systems has undergone a dynamic development over the past fifty years. The thrive towards more complex, holistic and detailed models covering multiple urban sectors al-ready dates back to the 1960s, trying to build more comprehensive and cross-sectoral models. Wilson (1970) from the Centre for Environmental Studies in London attempted a large-scale synthesis in urban modelling based on spatial interaction theory using the principles of thermodynamics and entropy-maximising analogies. These optimistic approaches of the early 1970s were followed by some disillusionment from urban planning and policy-making pinpointing the shortcomings of the models, which seemed to answer the wrong questions and leaving important issues concerning robustness of results in the context of volatile social developments and urban planning paradigms unsolved. In his trenchant article "Requiem for Large Scale Models" Lee (1973) summarises the critiques to these types of models as trying to represent too much complexity and answer too many questions at a time. The predictive value of the outcomes very substantially questioned. The consequences of these limitations in the following years of development lead towards a different approach to addressing the targets of urban modelling putting more emphasis on information and extended understanding of relationships rather than quantitative prediction (Batty 2008, p.11). Modelling as "story-telling" rather than prediction and simulation clearly leads towards more descriptive dynamic models for scenario analysis. Regarding the complexity and overall aims of models for urban energy systems this perspective seems valid as well. Rabino (2008) foresees a new challenge for future scientists and practitioners in the field of urban modelling having to join competences of both fields and working traditions. On the one hand a profound understanding of the urban problems to be solved, the historical background, political processes and planning methods to be used have to be put into the model and on the other hand the correct translation of systems behaviour and methods of mathematical problem solving is a precondition for useful model architecture.

Regarding the numerous sectors and stakeholders involved in urban energy systems these trends seem valid for energy systems models as well. Taking the step from simulation and prediction of outcomes and the idea of optimising certain limited

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criteria in a rather deterministic way, the principles of "systems thinking" opens pathways of combining quantitative and qualitative knowledge on the behaviour of agents involved in the field of energy supply and demand structures of cities and communities. As Donella Meadows puts it in her primer on systems thinking "The future can't be predicted, but it can be envisioned and brought lovingly into being. Systems can't be controlled, but they can be designed and redesigned. We can't surge forward with certainty into a world of no surprises, but we can expect surprises and learn from them and even profit from them. We can't impose our will on a system. We can listen to what the system tells us, and discover how its properties and our values can work together to bring forth something much better than could ever be produced by our will alone" (Meadows 2008 pp. 169-170).

Due to the actuality of the topic and the numerous ongoing research activities and developments, the chapter does not claim completeness. It might nevertheless serve as a contribution to overviewing this dynamic field of available methods and tools. From the review of existing methods and approaches some basic conclusions can be drawn: In order to support urban energy transition a general understanding of the existing energy system and the relevant actors is necessary. Equally necessary is the analysis of local potential and options for technological solutions. This can be regarded as the requirements for an expert modelling tool of urban energy systems. The frank knowledge on energy potentials and demands in a further step needs to be translated to clear messages and illustrative "pictures of development" for the decision-makers in charge, who are most often laymen in energy issues.

Urban planning and in the same context also urban energy planning in practice is not a deterministic straightforward process as implied by the outcomes of the models. Numerous actors with different interests are involved. Due to the mutual dependencies between municipalities, energy companies, building developers to only name the central players on the field, the outcome of planning processes is most often a consent compromise reflecting the individual assertiveness of positions. The outcomes therefore might deviate significantly from results or suggestions from experts' models. Confronted, practice beats theory and charming solutions may be neglected just because of inappropriate communication and interpretation interfaces. The situation aggravates with the fact that only very few planning processes on community level practically involve scientific expertise to minder this interpretation gap and build bridges to practice. Local decision-makers in most cases rely on their local experts and experience which is typically individual-related.

Being experts' systems by origin and aim most of the described models and tools stop before this next communication and translation step. From the scientific point of view this is consequent because summarising and explaining needs some simplification and reduction of complexity, stripping some of the scientific 'yes, but' statements to more simple messages with less information depth, losing some complexity on the way. Further research should take a closer look on these messages and their losses, limits and value for real planning processes and implementation. This should lead to an easier access to scientific results for local decision-makers, lowering the barrier for holistic, innovative and future-oriented solutions.

Regarding the initial research question “What tools are available and to what extent are they applicable to the context of small- and medium-sized communities and their planning authorities?” it can be stated that multiple tools are available. All of them origin from a scientific background and most of them are very complex. As a conclusion from the literature study I have to conclude that using models for energy transition is still not a common approach for communal decision-makers in the targeted communities. Regarding the second research question of this chapter “What are promising developments and simplifications for the communities in focus?” I regard the geographic reference a very promising background for energy transition modelling because of the high geographic impact energy measures have on space. The options and data requirements for GIS-based models will be looked at in detail in the following chapter four. Decision making demands a rather simplistic but reliable results. From the analysis of the existing models and approaches I draw the conclusion that a spreadsheet approach can supply sufficient accuracy to fulfil the targets of scenario building. A dynamic model is not a necessary precondition in this context. The model will have to integrate data of different sources and different aggregation levels. It therefore has to be transparent and clear and easy to handle. The preconditions for the data framework will be elaborated in chapters six, seven and eight.

4 Construction of a Scenario Approach in GIS

"There is no such thing as a favourable wind for the person who does not know where he is going."
Seneca

§ 4.1 Introduction

In order to build a model for urban energy systems on a Geographical Information System (GIS) platform and to add useful energy transition scenarios for the urban planning practice to this model, the conflicts of different approaches from different scientific disciplines have to be brought together in one model. Most urban planners are not very familiar with GIS or modelling. The everyday routines of planning are mostly about formal administration and legal procedures. Communication and the integration of stakeholders are important tasks as well. People working with models are commonly concerned with more abstract questions. They try to find optimal solutions under given preconditions or outline future developments. The beginning of modelling is always characterised by the definition of conditions under which the model shall be valid and the stating of a modelling question. Since urban (energy) planning is seldom concerned with mathematical optimisation questions but rather struggling with compromising and weighting of conflicting interests in implementation, a useful tool will have to bridge these differences to some extent. Geographical information systems offer functionalities to fulfil this expectation. The strong communication options and the rather open modelling characteristics of extended 'smart' mapping can result in acceptable and useful approaches to converge the different demands. In this chapter the characteristics of a GIS-based model for urban energy planning are elaborated. The focus is put upon the interactions of the different tasks of conventional and new urban energy planning and the synergies which may result from a targeted connection between different measures. The thinkable scenarios for energy transition are manifold as will be shown in chapter seven. In this chapter the guiding research question is how GIS systems can help to understand and analyse communal energy systems. The data framework is an important aspect and here GIS systems differ from other modelling approaches because all their information is positioned in geographical space. This is the case for any sort of chartable information be it spatial information or attributes and technical data. For energy systems this offers some advantages and additional analysis opportunities.

The following chapter gives an overview on commonly available and necessary data and their relation to communal energy systems. The research question to be answered in this chapter is how GIS systems help to understand and analyse communal energy systems. The previous chapters were concerned with general questions on energy transition visions, indicators and the methodology of modelling. The literature review of chapter three showed that geographic information may be a good basis for the display and analysis of energy systems especially to laymen as communal decision-makers. This chapter will give an overview on typical GIS-characteristics useful for the representation of energy systems in communities.

§ 4.2 Methodology

The GIS used in this thesis is ArcGIS 10.2.2 by ESRI Inc. The software already offers a broad spectrum of toolboxes and customised applications for all kinds of spatial analysis, visualisation and interpretation. So far there is no customised application focussing on energy systems and energy scenarios as addressed in this thesis. The options for analysis and visualisation already available in ArcGIS on the other hand go far beyond the scope of this thesis and will not be utilised for the case study analysis to which the model is applied in chapter eight. The beginning of the chapter is dedicated to the correlation between GIS information and the information needs for energy systems analysis. To examine the possibilities for an implementation specifically in small- and medium-sized communities it is important to understand the spread of GIS in today's planning practice. For an overview on existing approaches a literature study was done. Since the available data is essential for any modelling and scenario building, this chapter is addressing the research question from the perspective of the communal planner and the available data on hand. The availability of data is derived from the experiences in the case study and from literature.

§ 4.3 GIS characteristics for energy systems

§ 4.3.1 Information in space – information on space

A Geographical Information System (GIS) is a digital picture of the earth. It deals with the geometric and topological appearance of space. While maps are two-dimensional displays of geographical information, the computational power of today's picture and data processing and the plurality of available data add various additional layers of information to plain mapping. This extends the complexity and possible applications far beyond traditional cartography tasks. GIS allow fast and interactive access to geographical information and the creation of working environments with dense evaluation options.

The basic characteristics of GIS are rather simplistic in nature, representing space characteristics in points, lines and areas; aggregating, filtering, correlating and overlaying the represented elements for the creation of new information data sets. Coming from the most generic cartography background, GIS has developed to a propagated pragmatic general-purpose tool over the past decades. From its cartographic development history derives the fact that GIS systems were originally designed to deal with a-temporal spatial problems. Similar to most system modelling approaches a continuous flux in data and data updating is not foreseen.

The spatial data used in GIS comes from different sources and contains different data types. In this work mostly the ESRI-shape-format in combination with the GIS tool of ArcGIS is used. Shape-files can be read by many GIS-software products. The shape format archives the information in two data files. One data file contains the geometric data as points, lines or areas. The second file, a database file, contains the attribute, which are so to say the 'characteristics' of the points, lines and areas. An exchange with spread-sheet programs like Excel or Access is possible. Since not all data is delivered in a shape-file format, data can be converted by existing or specifically adapted converting programs to convert them into processible data and to give them a spatial relation.

§ 4.3.2 Implementing GIS for energy systems in urban planning

It can be stated that the degree of implementation of GIS in public administrations and the naturally every-day use of GIS applications or Planning Support Systems (PSS) is still far from widespread in small or medium sized communities. The assumptions of

Geertman & Stillwell (2004) and Vonk *et al.* (2007) seem to have been quite realistic in their pessimistic view. The constraints of expensive software tools and multiple and diverse tasks seem to be especially hindering for public organisations with inflexible procedural methods. Here the use of GIS is limited to very narrow tasks of plot accounting and infrastructure management and used only by single experts.

Traditionally GIS is used for the planning and administration of urban infrastructures. Roads, building lots and technical infrastructures are traditionally contents of the maps produced in a GIS. In this field it is closely related to computer-aided design and drafting. For administrative purposes, GIS systems offer the advantages of powerful database functionalities that have replaced analogue methods of data keeping in many urban administrative tasks. Urban managerial tasks demanded for systems to track and manage facility locations, natural resources and conservation as well as properties and tax accounting.

Despite its cartographic origin GIS offer numerous new fields of application in urban planning tasks and scenario building. The figurative presentation options facilitate communication. Because plans are less abstract than charts and tables laymen can usually understand the contents more easily. Since not only planners and geographers are familiar with reading and interpreting maps, GIS offer an interdisciplinary working platform. A central barrier for the implementation of GIS as a more wide-spread approach than the established planning tasks is the missing data basis and the complex data formats. Without a basic model to build upon, it is difficult to implement new sectors, for instance the sector of renewable energy potentials or options for smarter energy distribution.

The transition from paper-based to digital paper-less administration is an on-going, but nevertheless incomplete and inconsistent process. While basic sets of data are available digitally, especially official maps, there is no standardised digital procedure for the implementation of new and qualitative data. Applications for building permissions still have to be submitted on paper and are filed in lever arch files in the archives of the urban planning departments, transferring only basic and core sets of information to a GIS system. Especially for small communities with only few building applications per year, the effort for a digital registration of incoming data is out of a reasonable cost-benefit ratio. Small- and medium-sized communities mostly outsource their GIS data management and are supplied with customised new data sets from central land-registry offices. Therefore they usually only have access to limited attributes and administrative data sets that they handle themselves. Since updates of the geographical data are done irregularly and the implementation of minor changes (e.g. the demolition of building parts) is liable to charges, the maps commonly show quite some inconsistencies and mistakes. This has to be kept in mind when building models upon the existing map data.

A second aspect is the difference between geometric data and data on building qualities, which is essential information for any energy system. As will be shown for the community of Wolfhagen in chapter five there is hardly any development in the sector of new housing construction. The main activity in the building sector in the coming decades will be in the existing building stock. Refurbishments, alterations and conversions only affect the mapping environment if the geometrical outlines of the existing building stock are affected to a certain extent. Demolition of buildings and significant extension of existing structures are geographically relevant. Refurbishments and the change of use are commonly not. Therefore the discrepancy between the GIS information based on structural infrastructure and the real qualitative characteristics of the building stock increase over time. There is a great demand for harmonisation of data although the quantities of data sets and the speed of changes make a 'start when all data is validated' approach absolutely unrealistic. Quite a degree of uncertainty and mistake in data assumptions has to be accepted for the scenarios. Nevertheless the available data still holds good and valuable information that can be used to a greater extent than today. In order to build up a scenario model in GIS, the available urban planning information is used as a basis (chapter six to eight). Strategies to include non-geo-referenced data are described in chapter 4.4.3.

On the basis of this basic urban energy model, applied to the case study in chapter eight, additional modules are implemented that contribute to the outcome of different scenarios. The modules are described with specific emphasis on the urban planning perspective; therefore measures that need to be implemented by individual end-users are not specifically elaborated. From the perspective of urban planning, the aspect of how to motivate people to invest in efficiency measures or change towards a more energy conscious lifestyle are important questions. To avoid rebound-effects that consume the efficiency improvements on the technological side, it is important that decision-makers are aware of the relationship between different social milieus, lifestyles and energy consumption. A summary of the basic findings and consequences for energy system scenarios are given in chapter nine.

§ 4.3.3 GIS in energy systems

Energy use always has a geographic correspondence. Energy production facilities can be localised and energy demands can be assigned to an area. The distance between demand and supply has to be bridged by transportation, which as well demands infrastructure and occupies space. The planning and optimisation of transportation lines and grids is very close to the original core tasks of GIS in mapping and cartography. In the traditional energy infrastructures distance and space were rather non-sensitive aspects. Unfavourable geographic conditions, long distances and disparities between demand and supply, were addressed by increased power. Technical energy infrastructure, distribution grids and networks were part of the urban landscape as a matter of course and in its continuity hardly anybody paying any attention to them. Energy production sites were traditionally centralised large-scale industrial facilities, with great local but marginal regional disturbing visual or pollution effects.

With increasing shares of renewable energies, the urban landscapes change. With the trend towards decentralised production of renewable energy and the closer connection between demand and supply, energy infrastructures become more visible. Renewable energy production demands more scattered energy plants in the built-up and open landscapes. At the same time the public discussion on energy increases. The visual effects of renewable energy plants and the trade-off between the new technologies and the well-known familiar appearance of urban and rural environments occasionally lead to conflicts between politicians, investors and the public. In this context the energy discussion is most often both on land-use conflicts and on aesthetic perception. These conflicts have to be solved by urban planning as the responsible authority of land-use. As we have seen in chapter one, the core tasks of urban planning contain the basic functions of plan-making, development and regulation within the geographic outline of the community. Energy planning is a fairly new task in this context.

Until transition has succeeded with broad common acceptance of the new appearance of urban energy landscapes, GIS tools are able to help the planning and moderation process. In the process of transition the extended functionalities of the GIS serve as planning support systems to facilitate the transition process in small- and medium-size communities. The aim here is mainly to display the potentials of synergetic planning of the demand and the supply side and to illustrate the interactions between the different technological modules.

§ 4.4 Data framework and assumptions

In the context of data collection the central aim is to make information out of data. As Harris & Batty (1993, p. 189) point out, data does not make good planning and modelling does not inevitably lead to unambiguous best-plan solutions. The aim of creating a complete and consistent data set for all the relevant aspects of a communal energy system is utopic. Changes will occur faster than it can be kept track of them. The task of gathering and updating data sets would occupy inefficiently much time and attention without generating useful information. Important sources of data are the publically available maps and digital surface models. They form the backbone of the data set. This data is available from the official land surveying offices. In the following

TOC

the most important GIS data sources relevant for this work are described. The sources represent data standards used in German urban planning contexts and are based mostly on official cadastral and geographic survey data. The data situation in other countries is not an issue in this project because the application of the model in chapter eight is done for the German case study described in chapter five. The processing strategy of how to use geo-data for energy transition aspects is transferrable to other countries' conditions.

§ 4.4.1 Official topographic-cartographic information-system (ATKIS)[26]

ATKIS contains different components. Digital landscape models (DLM[27]), digital ground model (DGM[28]), airborne laser-terrain mapping (laser-scanning), digital surface models (DOM[29]), digital topographic maps (DTK[30]) and digital aerial photographs (DOP[31]) as raster data-sets. These will consecutively be discussed below.

Digital landscape models (DLM)

The digital landscape model contains similar information as topographic maps. The information is available as vectors, which can be displayed as point, lines or shapes. The objects in the maps contain attributes. The objects are structured in different categories: fixed points, settlement, transportation, vegetation, waterbodies, reliefs and specific zones (Figure 4.1). These categories are subdivided into object clusters and object types. For our research the DLM gives basic information on settlement extensions, roads and transportation infrastructure and on the structure and utilisation of the landscape, for instance forests, agricultural areas and protected habitats.

26 The abbreviation ATKIS stands for ‚Amliches Topographisch-kartographisches Informationssystem' and is held by the geographic offices of the Federal States in Germany according to a common set of rules. The actuality may differ slightly in the different states.

27 DLM ‚Digitales Landschaftsmodell'

28 DGM ‚Digitales Geländemodell'

29 DOM ‚Digitales Oberflächenmodel'

30 DTK ‚Digitale Topografische Karte'

31 DOP ‚Digitale Orthophotos'

The settlements are represented only by their spatial dimension, represented as larger connected arrays. In larger communities it may be helpful to use these settlement arrays to limit the size of detailed building and laserscan searches in the entire map. The settlement areas are usually bordered by roads. This way settlement blocks can be identified. The settlement areas are further differentiated by the assigned type of use, for instance residential zones, mixed zones, zones of specific uses or industrial zones. This can be an important first information for the identification of predestined surfaces for instance for solar energy production.

The zoning by utilisation can be helpful to verify the assigned building typology and to identify outliers in the dominating building structures that need to be verified on-site.

The transportation objects contain the roads as line objects with their width as attribute. Distances between buildings and roads can be calculated which can be useful for district heating concepts. It has to be stated though that the accuracy of the data is approximately ± 3 meters.

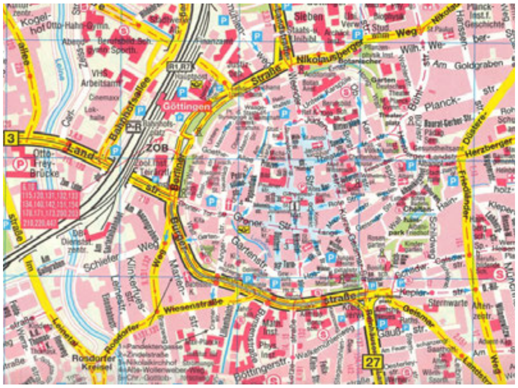


FIGURE 4.1 A typical application of DLM data are street maps. The different types of use can be identified by different colours.

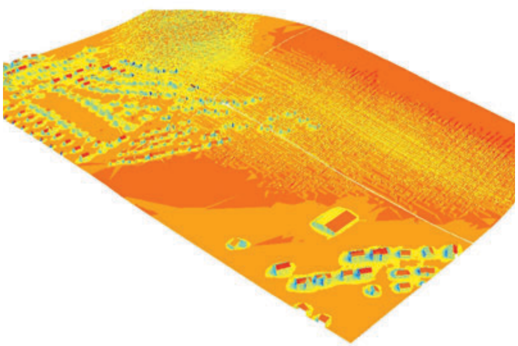


FIGURE 4.2 In the DGM 50 relief of the community of Wolfhagen only the rough topography is visible.

Digital ground model (DGM)

The digital ground model describes the relief of the surface. There is DGM data in different resolutions as DGM 1 / 5 / 10 / 25 / 50 available. The number indicates the resolution. The DGM 5 has a raster resolution of 12.5 meters and an elevation accuracy of 0.5 meters. The data is collected via topographic ground surveys, photogrammetry and today increasingly via laser-scanning. The DGM 50 has a grid resolution of 50 meters and an accuracy of a couple meters. There are possible deviations of up to ten meters. The DGM 1 and DGM 5 are not yet available for all areas in Germany. The DGM

50 is often available for free or at very low costs but gives only a very rough idea of the surface relief (Figure 4.2). The DGM is based on airborne mapping. The low resolution of the DGM 50 allows the display of surface elevation and topography but is not precise enough to represent the built infrastructure.

Airborne Laser-Terrain mapping

Laser-scanning data is collected via airplanes. The earth's surface and all objects on the surface are systematically scanned by a laser-beam sent out from the airplane. The laser-beam is reflected from objects and the surface and received by a sensor in the plane. By a rotating or pivoting mirror, fan-shaped laser-beams are produced diagonally to the flight direction. By the movement of the plane the surface within the strip is scanned (Wever and Lindenberger 1999) (Figure 4.3). The identification of the 3D position of the obtained data points is accomplished by combining the information from three different systems: a GNSS-receiver, a global positioning system (GPS), tracks the position of the airplane. By an inertial navigation system the attitude of the flight is measured (angles orthogonal, perpendicular and along the flight axis).

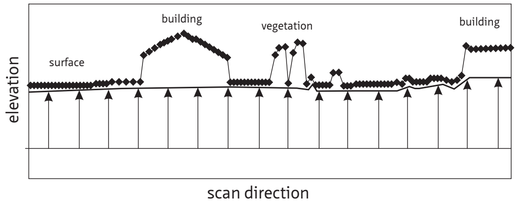


FIGURE 4.3 The data cloud can be interpreted regarding different criteria. (after Axelsson 1999)

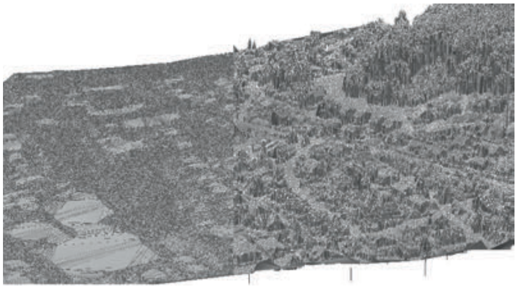


FIGURE 4.4 DTM and DOM of Kanton Zürich (from geolion.zh.ch/geodatenservice)

The achieved precision of the measurements are approximately 15 cm in height and 30 cm on the surface. There are usually several points per square meter. The result of a laser scanning is a cloud of data points that can be processed and interpreted further (Figure 4.4). The first classification is done by surface points, non-surface points and other points. The surface points are used the DGM maps, the non-surface points give information for the digital surface model (DGM).

Because of the high precision laser-scanning data is very valuable for digital 3D town profiles. From the data building heights, roof areas and slopes can be derived in great accuracy. The validation of building geometries is an important factor for the assessment of energy demands. The shading situation and roof areas supply useful information for passive and active solar energy potentials. At the same time the processing of laser-scanning data is very time consuming and demands a great level of experience in interpretation.

Digital surface model (DOM)

With the laser-scanning data it is possible to classify and describe the objects on the surface, for instance as buildings and vegetation. The laser points are not spread evenly over the surface. By interpolation a regular raster can be created out of the point cloud. The raster allows an efficient data processing. On open spaces the DOM matches the DGM. In areas covered with buildings, forest or other permanent vegetation, the DOM follows and represents the heights of the objects.

Digital aerial photographs (DOP)

Digital aerial photographs are created by the differential rectification of the original aerial photographs. This way the DOP can be geo-referenced. The resolution ranges from DOP 10, with a surface resolution of 0.1 meters, to DOP 40, with a surface resolution of 0.4 meters. The photographs are mere pictures in jpg or tiff file formats. In the GIS they provide important information for the identification of single objects that cannot be clearly identified from the maps (Figures 4.5 and 4.6).

FIGURE 4.5 Aerial photographs provide high resolution information on elements that are not represented in the maps, e.g. different types of use in a mixed quarter.

FIGURE 4.6 Or wind energy plants.

§ 4.4.2 Official cadastral land register (ALK[32])

The cadastral land register is used as the official register of real estate. To keep the information up-to-date the land register has to be maintained continuously. This is the responsibility of the central cadastral offices responsible for the communities. The ALK contains the distribution of the surface area in single plots of land (Figure 4.6). The outlines of buildings are elements in the cadastre. The accuracy of the geometries is very high. The data is obtained by terrestrial measuring on site. In addition to the geometrical data the plots and buildings contain additional attributes, for instance the type of use and street names and numbers.

32 ALK ‚Automatisierte Liegenschaftskarte'

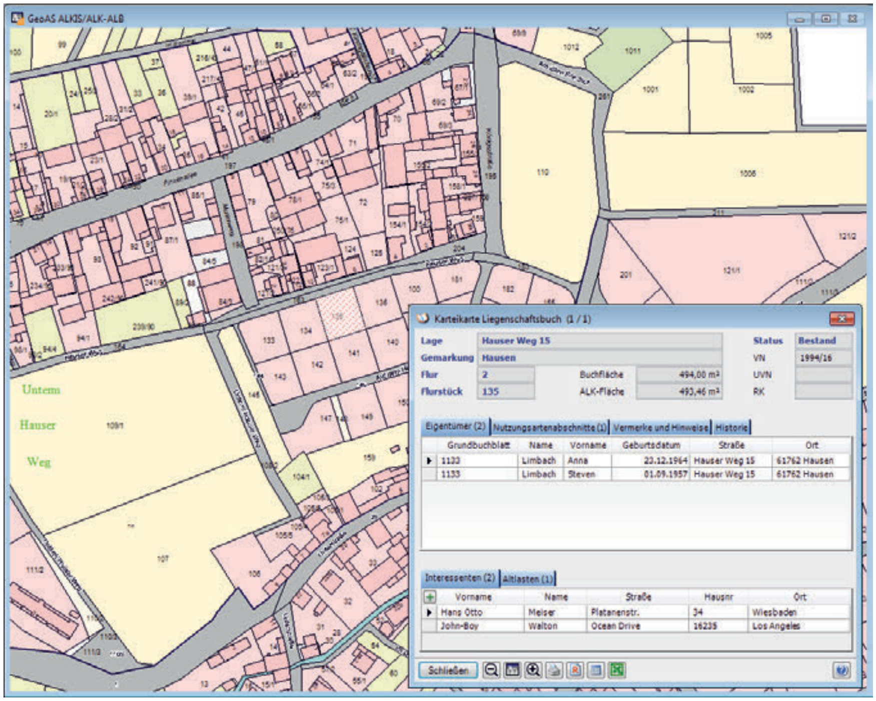


FIGURE 4.7 Example of an ALK and ALB application. The plots are labelled by numbers and the type of use by colours. In the ALB database the owners and addresses are archived. (from agis GmbH, Frankfurt a.M.)

The ALK is very helpful for the digital model of the community. The very precise geometry of the building ground area can be used in combination with the height information from the laser-scanning to estimate building volumes. In the ALK the building geometry is based on the legal ownership structures. Therefore terraced houses are represented as individual buildings, whereas in the laser-scanning data they would appear as solid building blocks.

The cadastral land register is available for communities for their own analysis and to some extent for maintenance of the data. It contains detailed and essential information for the setting-up of an energy demand map of the community, because the building related geometries can be assigned to typologies or detailed energy demand surveys. The ALK is the data framework that the employees at the community planning departments are most familiar with. It forms the back-bone of the GIS energy model for the built environment.

§ 4.4.3 Non-geographic information

To use data in GIS it is necessary to assign a geographic reference to the data collection which is often available as statistics. Statistics are available referenced to certain areas, to specific person groups or for specific boundary conditions. Therefore it is necessary to have a basic framework of information to which the statistical data can be applied to. To get a first display of the local situation the use of statistical data is a good first approach. Starting from statistical core information more specific local data can be added step by step. Statistical data which is available with reference to the inhabitants is easy to display geographically, because the number of inhabitants is known with high precision. For instance consumer specific data can be generalised and used from statistics to obtain a first estimation of the energy consumption sectors, which are not directly connected to the built infrastructure, for instance as by Schächtele & Hertle (2007). The use of statistical data has the additional advantage of being non-critical regarding the issues of personal data protection. Wherever data is used for communication and public access, statistical data on energy consumption per capita is a good approximation (Table 4.1).

SECTOR	EMISSION TYPE	DATA SOURCE	CO_2-EMISSIONS PER CAPITA [t/a]
Transportation	CO_2-equiv.	(Schächtele & Hertle 2007)	2.52
- Passenger Car	CO_2-equiv.	(Schächtele & Hertle 2007)	1.56
- Public Transport	CO_2-equiv.	(Schächtele & Hertle 2007)	0.11
- Air Traffic	CO_2-equiv.	(Schächtele & Hertle 2007)	0.85
Food	CO_2-equiv.	(DeStatis 2011)	1.65
Health and Social	CO_2-equiv.	(DeStatis 2011)	1.24
Private Consumption	CO_2-equiv.	(DeStatis 2011)	2.75

TABLE 4.1 Examples of statistical data per capita that can be used as approximation in scenarios (from Schächtele & Hertle 2007)

The same procedure can be applied for the visualisation of other non-geographic data, for instance results of inquiries.

§ 4.4.4 Convergence of different data levels

It is a very disappointing experience to encounter large white spots on a map if you are looking for specific information. In former times of the great discoveries, white spots on the maps might have stirred the spirits of navigators and explorers, today in our digitalised and data rich world, they leave the impression of incompleteness. Obvious blank spots are very unfavourable for scenarios, because the message becomes very blurry. Especially for the important communication tasks, blank spots in the representation of the scenarios should be avoided.

It shows that under the given uncertainties of data, it is better to discuss scenarios on the basis of rather rough approximations of data, for instance by using standard values and statistics, than not discussing scenarios at all. The central idea is to start already at a fairly simplistic level and to enable the community to improve the data basis step by step continuously.

To fill the model with data, a three level input structure is used in this thesis. A first basic level is filled with the static data on a high level of generalisation (e.g. from Department for Communities and Local Government 2012). On the second level the data is differentiated according to additional specific local information. The third level is specific measured data. It could be assumed that there should be a preference to obtain the third level data for the model, since it comes closest to 'real-life' (Figure 4.8). Nevertheless all three input levels have some pro and cons that we have to be aware of for proper interpretation of the outcomes.

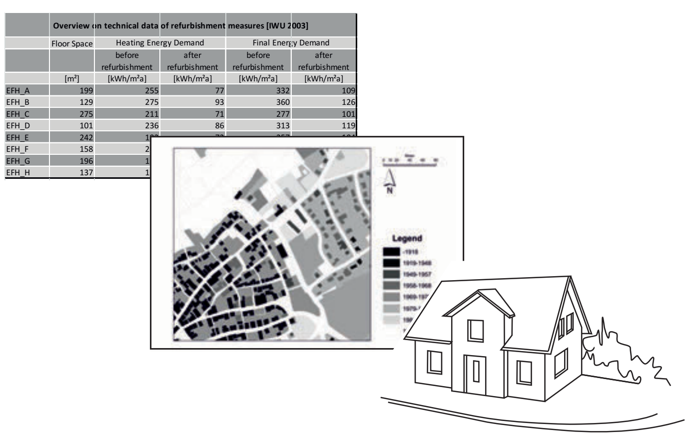


FIGURE 4.8 Different data levels supply differently aggregated and specified information. Information on energy demands of buildings can be supplied by statistics, building typology or detailed analysis, for instance from an energy certificate.

Statistical data supplies general data; it represents the average over a certain coverage entity. The geographic reference to statistical data correlates to the areal reference of the enquiry, for instance the development of the population in a country, state, district or community. Some useful statistical data comes from scientific studies, for instance the average energy consumption for transportation per person, as presented by Schächtele & Hertle (2007). Statistical data can be used in the most differentiated version that is available and serve as a robust first data framework for important aspects of the model. Statistical data, in many cases, shows a rather stable development over time. The general characteristic of the data entails that in any specific application, the data might show maximum deviation. The more specific the questions to the scenario become the less sufficient is statistical data. At the opposite end of data sphere is the measured or enquired data, for instance the electricity consumption of a household or the number of cars owned by a family.

Measured data is of great accuracy and essential for any planning and optimisation process. Measured data is always site-specific and geographically assigned. Refurbishment measures on buildings for instance, are planned on the basis of a detailed data acquisition of the existing building components. Data enquiries consume a lot of time. This is the greatest barrier for the analysis of a communal energy system. Although the idea is tempting of modelling with measured 'real-data', for a scenario model there are also some disadvantages. Within the complexity of a communal energy system there is continuously change going on somewhere. Letting alone on going refurbishments and changes in user patterns, the dynamics of reality lead the attempt of modelling with enquired data ad absurdum. Data acquisition and updating would never be fast enough to constantly feed the data demands of a model built on collected data. What was principally valid for statistical data holds reciprocally for measured data: The measured data might be far from average because of exceptional user-patterns or very specific building conditions. From the particular case no universality can be concluded. To obtain a consistent picture many data points are necessary. Nevertheless measured data is essential or monitoring of the results and the validation of assumptions in a specific case.

In-between and less well definable, is what is indicated as 'level two information' in Figure 4.8. This is statistical data enriched with specific local information to make it more precise. The general information on solar energy potential can be specified according to the roof area, slope and orientation. This makes the information more valuable for the scenario without the need for elaborate field studies. The sources of information for this level are numerous and differ from module to module.

For the scenario and the long-term maintenance of the data base it is important to indicate the data source and the level of detail of the data used in the GIS. This way a continuous improvement of the data base can be achieved with the option to work on individual data sets separately. The overall picture in the scenarios will always represents the data situation of the community, from a static and geo-data-based overview to the specific outcomes based on on-site data acquisition. The data base character of the GIS allows a clear tracking and monitoring of the data origins. The GIS can represent the areas where the different data levels prevail. This can help when interpreting the scenario results. After the implementation the GIS data base can continuously be updated and completed with new data sets. This way the understanding of the energy situation becomes better and the scenario results more tailored.

§ 4.5 Conclusions

GIS offer good opportunities to build energy transition scenarios for small- and medium-sized communities. This is because the geographic visualisation facilitates communication with laymen from the different interest groups. Since communication and mediation in the context of urban planning is already a central task for communal planners it makes sense to base energy transition models and scenarios on a good communication platform. This is especially important since most issues of decentral energy transition have a strong relation to spatial attributes. This concerns energy potentials as well as energy distribution. Even energy consumption aspects are closely related to buildings and can be easily referenced in GIS. Even non-spatial or statistic data can be referenced and displayed. The option to display and process a broad variety of data sources makes GIS a flexible tool for the purposes of energy transition management. For complex systems with large amounts of different data the data base structure of GIS is favourable. For modelling and scenario building it is favourable to be able to work with incomplete or inconsistent data sets. For small- and medium-sized communities it is possible to apply a first level of analysis based on statistical and typological data and continuously specify data if necessary. Here a sectoral specification is possible, since not all data sets need to have the same integrity. The basic geographic data for a GIS based energy transition scenario building is available for communities of all sizes and should not be a severe barrier for implementation. The available toolboxes and applications in ArcGIS offer a broad variety of visualisation options and map interpretation tools. Only a small fraction of these tools are used in the limited scope of this thesis. For urban developments on larger scale 3D visualisation can be considered state of the art. Generally there are trends towards high performance visualisation and animation in both CAD and GIS, for instance in the ESRI CityEngine, which is focussing mainly on 3D virtual reality visualisation. So far energy system transition is not a typical application offered either as product application or service. Especially communities of smaller scale are usually not addressed in high resolution 3D city models. Small- and medium-sized communities nevertheless offer good boundary conditions to field-test the possibilities of energy transition scenarios on a GIS basis. In this thesis the central focus is put upon the data and the effects the key factors of the energy system have on each other. Regarding the future development of visualisation there is certainly a high potential in this sector. As well the implementation of timeline analysis will facilitate the building of scenarios. In this thesis the scenarios are basically a precast stack of maps. In the future the options to process big data in feasible time will make these applications much more dynamic.

This chapter answers the central research question of this chapter "How can GIS help to understand and analyse communal energy systems?" in a twofold way. On the one hand GIS offer an attractive and easy-to-comprehend communication platform. This is favourable for all participation and communication processes where laymen are involved. Secondly energy and especially renewable energy has a strong geographic impact. Consequences and limits of measures can be represented in a spatial relation.

The following chapter five is given an overview on the general and energy related boundary conditions of the case study of this thesis. In chapter six the data framework will be described. As already mentioned in this chapter, data aggregation and convergence is an important issue when dealing with many different data sources. Therefore chapter six is divided into a section on general (statistical or large-scale) data and specifications available for the case study. On the GIS platform the data is merged into the scenario evaluation in chapter ten.

5 Case Study description: Wolfhagen

"When it's urgent it is already too late."
Talleyrand (1754 – 1838)

§ 5.1 Introduction

In this chapter the case study community of Wolfhagen is introduced and described. An overview is given on the development over the past decades to understand the context of the case study situation and to frame the data in chapter six, the scenarios in chapter seven and the application of the scenario modelling in chapter eight. For the research work the town was chosen as a case study because of the numerous activities going on in the fields of energy efficiency and renewable energy. Many energy efficiency and renewable energy projects have already been realised in the community of Wolfhagen over the past decades. This is mainly the achievement of local actors from the town's utilities in combination with a positive and supporting town council and mayor, representing an interested and engaged population. In this chapter the history of the energy transition project in Wolfhagen is outlined and the on-going developments are described. The central research question of this chapter is what central data characteristics describe the community as a case study. Here the focus is more on the adjacent and soft factors for instance the local initiatives and research activities of the past years. The specific data for the scenarios is given in the 'B-sections' of chapter six, seven and eight. This chapter shall facilitate the interpretation of the scenario results by a better understanding of the greater context. In several aspects Wolfhagen is both a quite typical and quite special case study. Typical is the town's structure and size; typical are as well the problems of population development, demography and the critical financial situation of the communal household. Exceptional are the local initiatives for energy efficiency and renewable energy. These are often initiated by the local residents and supported through the good cooperation of different local groups with the local government and utilities. The projects have cooperated with universities and research institutes in the past with some good success. The participation and the outcomes of the different projects form the basis for the long-term transition project under the funding scheme of "Energy Efficient Cities" of the German Federal Ministry for Research and Education which is the central and most ambitious on-going activity. In this chapter a status quo is given on the present situation in the community.

The connection to real life projects and their progress bears both chances and risks for research and especially thesis projects. On the one hand the link to real-life implementation and processes makes realistic solutions and approaches more probable than in laboratory analysis and modelling. On the other hand progress in research is highly dependent on the progress of the transition process in the community's administrative and decision-making progress. The field study is intended to deliver some insight into the practicability of the developed approaches regarding transition visions, indicators, scenario building, expert modelling and communication. My cooperation with the community started in 2008, in the context of a competition call published by the German Federal Ministry of Research and Education. This call addressed towns and cities with ambitious and holistic energy transition projects and visions. The participation was successful and the national research project started in the beginning of 2012. The aims of the transition project in Wolfhagen were very similar to the targets of the Dutch project EOS-LT: Duurzame Gebiedsontwikkeling and the case studies addressed there. This allowed cooperation for this thesis project.

§ 5.2 Methodology

For this chapter the available reports and studies for the case study were analysed and evaluated. Past developments and projects realised were gathered mostly in personal interviews with the local stakeholders. From this an overview is given on the greater context of the energy transition in Wolfhagen. The status quo analysis of the Wolfhagen energy system founds on several data sources and is collected in chapter six. The aim is to create a holistic picture of the present day situation to allow interpretation and results from the scenarios and to put them into a proper context. For the status-quo analysis several reports and existing specific analyses could be used. For instance, both the city report of Aring *et al.* (2010) and the report of Bergholter & Ettinger-Brinckmann (2010) on the roadmap for the historic town centre contain general data on the community. In January 2010 a household inquiry on the energy related sectors buildings, electricity consumption and transportation was sent to all households in Wolfhagen. The inquiry intended to gather a broad spectrum of data and personal opinions regarding refurbishment measures, renewable energies and consultancy and information demands. In addition to data on the current situation of the building and the residential structures qualitative results were gathered that are not represented in statistical data (Figure 5.1).

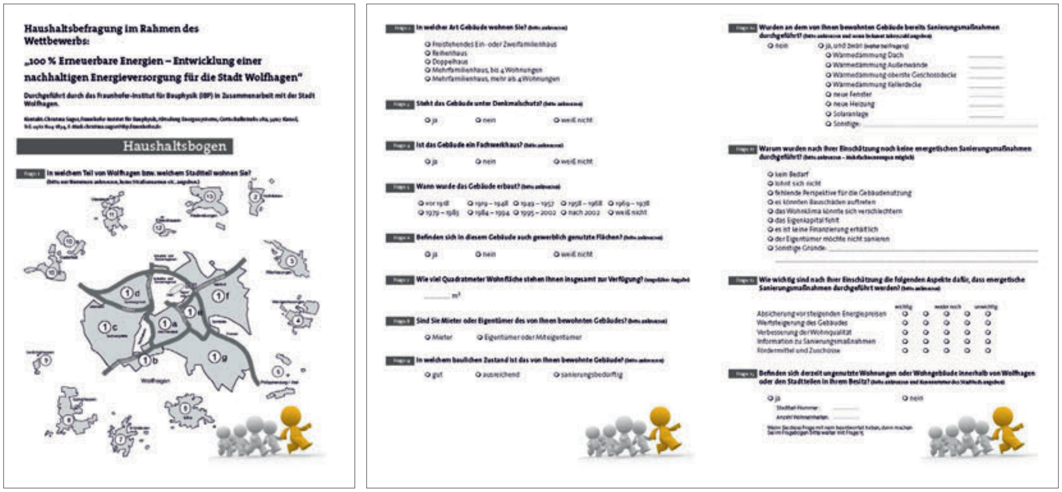


FIGURE 5.1 First three pages (of eight) of the household inquiry document.

In total 6,300 questionnaires were sent to the households. The questionnaire contained 44 questions on the building and refurbishment measures, energy consumption, mobility and the consulting services in Wolfhagen. The mailing was done with the free-of-charge local newspaper, which is distributed every other week to all households. 548 questionnaires were returned, representing a return rate of 9 %. Although the return rate was lower than expected, perhaps resulting from the high number of questions, important information can be derived from the questionnaires returned. Regarding the representation of the population in Wolfhagen the return shows a good match for the age structure, the age group above 65 years was slightly overrepresented in the inquiry. With the household inquiry several questions should be answered. One aspect was to obtain enough comparative data to evaluate the deviation to the communal statistics. Another aspect was to gather qualitative responses on options and barriers to take efficiency measures and renewable energy technologies.

§ 5.3 Previous developments in Wolfhagen

At present numerous actors play an active role in the energy transition process of Wolfhagen. The competences involved range from local residents with their different professional backgrounds to the employees of the communal utilities to the public body in the different administrative departments. Starting from initiatives launched by only few, energy issues are very present in the community. The activities connected to the energy transition process in Wolfhagen can be structured in four fields of action:

1 Political strategy
2 Coordinated implementation and investments
3 Public action and initiatives
4 Research projects

Some of the activities already date back several years. This emphasises the fact that transition processes need rather long periods to gain momentum and develop impact. The highlights are shown in Figure 5.2:

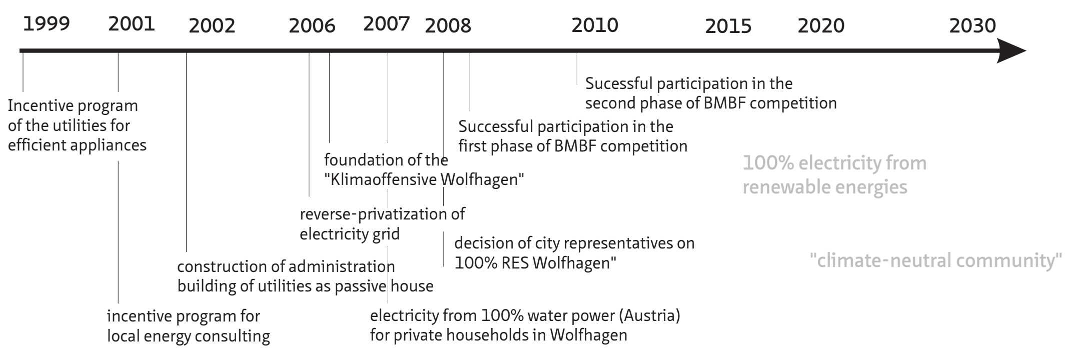


FIGURE 5.2 Timeline of the most important communal decisions in the context of the energy transition.

A sustainable energy transition in a rural, spacious and by demographic community and economic change affected is at a time challenge and chance. The question how in economically difficult times population, institutions and politics can find the will and endurance to implement necessary steps in a new and different direction of energy transition, will be the core question of success or resignation. The realisation of local options in the framework of national politics plays an important role. Energy transition processes are described and addressed by numerous projects and authors. Most find two different approaches towards a vital transition process worthwhile: either the "top-down" development of an urban transition strategy and vision and the definition of projects that comply the strategy or the more "bottom-up" development with an innovative project serving as "kick-off" for a process initiative that accelerates and gains impacts over the growing interest and involved circles over time (Figure 5.3). This is about the development of the transition process in Wolfhagen, with the renewable initiative of the utilities at the beginning. It can be stated that the Wolfhagen initiative roots in the continuous and ambitious activities of very few stakeholders. In the course of time their perseverance attracted other actives that complemented with their initiatives and interests to the overall development.

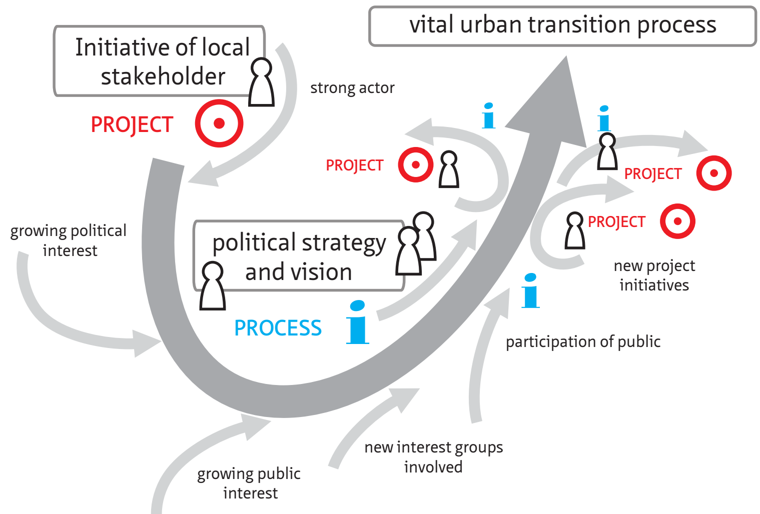


FIGURE 5.3 In a successful transition process acceleration from initial projects lead to a multiplicity of involvement and projects.

Wolfhagen has good preconditions to become a model community for energy transition. The city is small enough to oversee all relevant sectors and fields affected and big enough to show representative problems of structural change to be approached and addressed. Solutions that succeed or fail in Wolfhagen can hopefully help similar communities with basic solutions and strategies. The success of the community to realise projects and start initiative from different corners of society grounds on four central issues which will be described in the following:

- Political strategy
- Coordinated implementation and investment
- Public action and initiatives
- Research projects

§ 5.3.1 Political strategy

Even though the Wolfhagen town council has not yet started a formal energy development plan process, energy efficiency and renewable energy have been a core topic of the town's political strategy since the millennium change. The early developments and programmes were initiated mainly by the local utilities with several public incentive programmes for energy-efficient appliances and household energy-saving advisory service. The local utilities are in 100 % ownership of the town and therefore the initiatives of the public services are closely connected to the town's strategy. In 2003 the members of the town council decided to buy their electricity grid back from the E.ON Mitte AG. In 2006 the de-privatisation was completed and full influence on the local electricity distribution regained for the local energy service company. This was novel in the state of Hessen at the time and has served as model case for several communities in the following years. On the 17th of April 2008 the communal councillors decided to develop a 100 % renewable electricity supply for the town's households. This was as well the starting point for the planning process of the privately owned wind park, one of the large initiatives of the utilities until today. The final step in the political strategy was taken on the 1st of March 2012 by the decision of the communal councillors to allow the local population a 25 % ownership of the local utilities. This is an innovative step towards a more democratic and customer oriented energy supply. The energy cooperative was officially founded on the 28th of March 2012 by the BEG Bürgerenergiegenossenschaft (www.beg-wolfhagen.de). At the same time the utility companies founded a regional cooperative of communal utilities in Nordhessen called SUN Stadtwerkeunion Nordhessen (www.sun-stadtwerke.de), to support and advice utilities in their re-privatisation processes and the integration of greater quantities of renewable energy.

§ 5.3.2 Coordinated implementation and investments

Parallel to the political and strategic activities of the city and the utilities, a number of investment and implementation projects were started to emphasize the role model function of the city. In 1994 the first photovoltaic plant on a communal building was connected to the grid. In December 2001 the utilities completed their office and service building in Wolfhagen. It was built in Passive-house Standard and is supplied with a heat pump and photovoltaic panels, so self-sufficient supply is possible. The new fire department building in Bründersen was completed in 2010. The building is supplied with heat pumps coupled to solar thermal collectors and an underground storage. The supply system was contracted from and is operated by the utility company. On a larger scale of city development the planning department approached the question of energy efficiency. In 2008 the old town centre of Wolfhagen was chosen for the city development program Aktive Kernbereiche in Hessen - 'active city centres in Hessen' (www.aktive.kernbereiche-hessen.de). This enables the town to invest in measures for urban enhancement and structural strengthening. The plan for the integral set of measures was finally passed by the city council on the 10th of June 2010. In the year 2009 the town dedicated her participation in the Fachwerk-Triennale (www.fachwerktriennale.de) to energy-efficiency issues in historic timber-frame constructions to raise attention to the specific demands and difficulties of this historically important type of construction. Every three years this event series is organised in historic timber-frame cities and towns. In 2009 the German Federal

Government decided to launch a second economic stimulus package to ease the effects of the financial crisis. The city of Wolfhagen decided to use the available subsidies mainly for energy refurbishment measures in schools and the city hall. Even though the Federal government did not restrict the spending of the subsidies the city of Wolfhagen clearly put the priority on efficiency measures.

§ 5.3.3 Public action and initiatives

From the beginning local residents actively participated in the energy activities of the community. In 2006 37 residents founded the 'Klimaoffensive', a private interest group to enhance energy-saving and efficiency in Wolfhagen. The core group consisted of residents of Wolfhagen, who tried to raise awareness for efficiency measures and renewable energies in a loose succession of workshops, publications and events like discussion forums and movie presentations. The local initiative was actively supported by the energy agency of the district, Energie 2000 e.V., which resides in Wolfhagen and mainly aims at supporting energy-efficiency projects and carries out the energy advisory services for households and building owners. With the beginning of the private wind-park project the local utility company initiated a public participation and discussion process, in which the potential locations were presented and discussed in several forums and the media. From the very beginning there were concerns against the most potent location on top of the forested Rödeser Berg. A group of local residents founded an interest group against the wind park at the forest location (www.kein-windrad-im-wald.de) and organised demos and campaigned with the collection of signatures against the project during 2010 and 2011. On the other side the supporters of the wind park and the energy transition process organised themselves in an interest group to strengthen the initiative. A period of severe discussions and controversies followed until the beginning of the formal planning process. To communicate the goals of the wind energy project in Wolfhagen the utility company supported a documentary film project that addressed the pros and cons of the different interest groups. The 'wind of change' *Wind des Wandels*[33] was played in the local movie theatre for about two weeks and with special presentations for schools and interested groups. In the preparation phase of the energy cooperative a participation workshop was organised as 'future workshop' *Zukunftswerkstatt* to offer the interested public the chance to participate and contribute expectations and concerns. At this workshop on the 10th of March 2012 all running and initiated energy projects were presented at eight discussion points.

33 Available at: www.windpark-wolfhagen.de/index.php?page=20

§ 5.3.4 Research projects

Communication and participation of the public was as well a core issue in some of the numerous research projects Wolfhagen is involved in. With growing attention to climate and energy issues, the city of Wolfhagen became interesting as a case study for researchers who aimed at supporting the city and its activities with work and advice. The first research project Wolfhagen was involved in, was funded by the Ministry for the Environment, Energy, Agriculture and Consumer Protection of the State of Hessen. Three communities were involved: Wolfhagen, Eschwege and Lichtenfels. All of them were of similar structure and boundary conditions. The aim of the project was to initiate a communication process in the communities and to identify a roadmap to reach climate neutrality in the communities (Figure 5.4). Several local workshops were held and evaluated. The results were summarised in a guideline publication (deENet 2010).

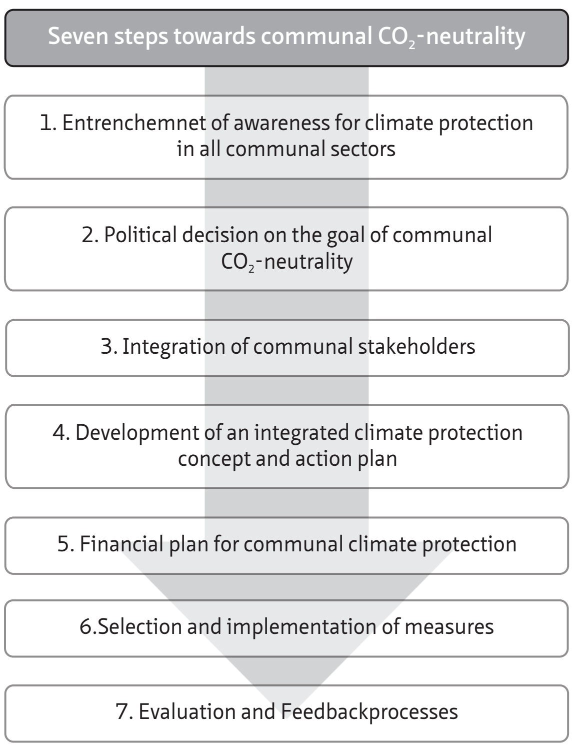


FIGURE 5.4 Seven steps towards communal CO_2-neutrality defined in the scope of the “Strategien von Kommunen zur Erreichung von Klimaneutralität” project.

The outcome of the project was seen quite critical by the community council, since by the finalisation of the project the implementation of measures had not yet started and the practical outcome of the numerous workshops was quite vague. Since the entire project was focussed on a consultation and conceptual process, the necessary investments and action would have needed to be continued after the official termination of the project. Since the action plan did not succeed in building a functioning task force for implementation, the impression was left at the community council and the local utilities of being just a study object without gaining much surplus value out of the research participation. This fact led to some scepticism towards new research projects and the strong maxim that any research has to result into 'action on the streets' of Wolfhagen. A smaller research activity is connected to a European project in the 7th Framework Programme called "InContext – Individuals InContext" and elaborates questions on how to enable people towards a more sustainable lifestyle. Wolfhagen is one of the cases and several interview partners from the city will contribute their experiences and developments throughout the project[34].

In the preparation of the wind park, the Fraunhofer Institute for Wind Energy and Energy System Technology integrated the designated wind park location Rödeser Berg into a research project funded by the Federal Ministry for the Environment. To evaluate the wind energy potentials inland, a 200 m high measuring pole equipped with instruments was installed to evaluate wind velocities between 40 and 200 m above ground. The results contribute to the planning of the Wind Park and serve as reference data for other locations. The participation in the Federal competition of 'Energy Efficient Cities' launched by the Federal Ministry for Education and Research and the project success is so far the last step stone in the line of successful transition projects in Wolfhagen. In the contest Wolfhagen participated with an interdisciplinary consortium of research organisations, local actors and communication organisations and succeeded to convince the jury in the two stages of the competition. This project will form the backbone of the financing of the transition process in Wolfhagen over the coming years until its termination in 2017.

§ 5.4 Communal Structure

The total community area is 112 km², of which 12 % are buildings and infrastructure, 34 % forests and 52 % agricultural areas. The city of Wolfhagen is categorised as a middle order centre and is located 30 km west of the higher-order centre of Kassel and 70 km south of the higher-order centre Paderborn (Figure 5.5).

34 see: http://incontext-fp7.eu/

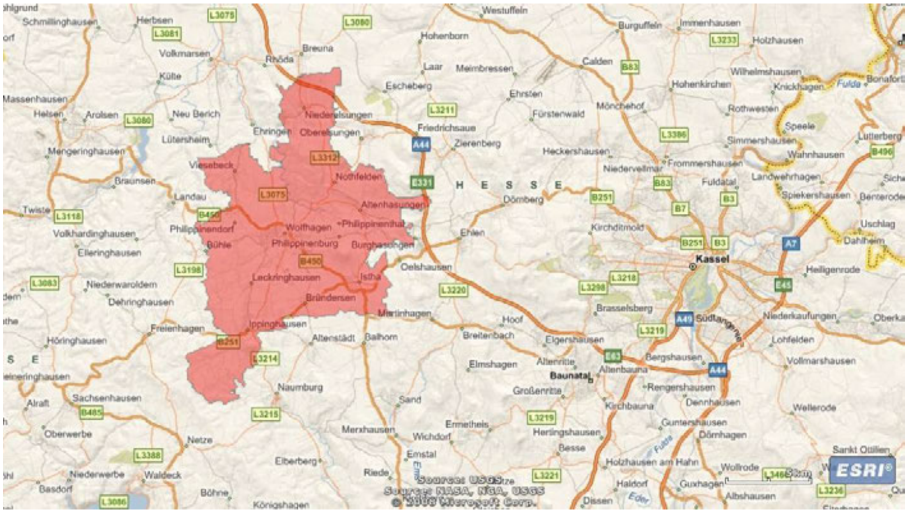


FIGURE 5.5 Wolfhagen community in the context of the surrounding cities and towns.

Via the national highway A44 Wolfhagen is comparatively well connected to the lager region. The central city is connected to Kassel and Korbach by a regional train. Wolfhagen has a 30-minute interval connection to Kassel and an hourly connection to Korbach.

§ 5.4.1 Central town and villages

The community of Wolfhagen consists of the central town of Wolfhagen and eleven mostly village-like town districts. The town of Wolfhagen is located in the centre of the communal parish with the villages scattered around (Figure 5.6). The villages are connected to the central town and the train station by busses or hailed shared taxi connections. The total number of residents is 13,804 inhabitants of which 7,674 reside in the central city (Table 5.1).

TOWN DISTRICT	INHABITANTS (FEB. 2012)[1]
Wolfhagen (town)	7,674
Philippinenburg und -thal	181
Altenhasungen	695
Bründersen	646
Gasterfeld	219
Ippinghausen	1,142
Istha	951
Leckringhausen	47
Niederelsungen	978
Nothfelden	389
Viesebeck	337
Wenigenhasungen	545
(Elmarshausen)	22
Total	13,804

TABLE 5.1 Number of residents in the town and the districts.

1 source: http://www.wolfhagen.de/de/rathaus/zahlen_fakten/einwohnerzahlen.php?navanchor=1110036; checked on the 24th of May 2012

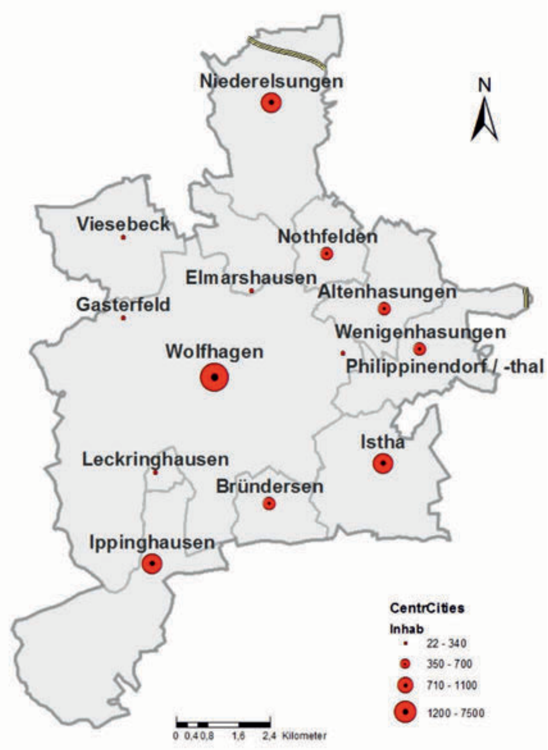


FIGURE 5.6 Location and size of the districts.

The centres of the town and the villages are dominated by historic timber-frame constructions (Figure 5.7 and 5.8).

FIGURE 5.7 Historic timber-frame constructions dominate the old centres.

FIGURE 5.8 Large-scale timber-frame buildings represent typical old farmsteads in Wolfhagen.

Central and important services offered in Wolfhagen are the vocational schools in Wolfhagen and at the former military site '*Pommernkaserne*' in Gasterfeld. This makes Wolfhagen an important educational centre of the area. The city of Wolfhagen intends to focus its commercial development to the conversion area of the former military site of the *Pommernkaserne*. Adequate areas for the civil use are available at the former casern area (42 ha) and at the former military training area (275 ha). On the site there are fairly well refurbished buildings of different types and sizes. Next to halls, workshops and storages there are education, residential and commercial buildings, a gym and outdoor sporting facilities that could be used for education, science and commerce. A railroad track connects the site to towards the city. This connection is currently closed but may serve as a nice local transport option in the context of the future developments on the former military site.

At the beginning of planning of the redevelopment, the city of Wolfhagen supported the foundation of an international university for vocational training. These plans failed because of changed priorities of strategic development of the cooperating university. In spite of this drawback the conversion of the facilities developed successfully. With the final withdrawal of the national forces on the 30th of June 2006, 50 % of the sites were brought to market. One of the new users is a glass production company '*Energyglass*' with 50 employees, who produce high insulation three-pane efficiency glasses for the building sector. The company plans to extend their production in the near future. The refurbishments and reconstructions for the new vocational school centre '*Herwig-Blankertz-Berufsschule*' is completed and has started education in summer 2010. In the previous year, the largest building integrated photovoltaic plant in Hessen was put into operation on the roof of the former tank garages now used by the school.

The company '*Kuntschar energy technology*' has started the operation of an innovative block heating power plant with an electric power of 50 kW_{el} at the site. The plants operate with wood gas extracted from wood chips. The heat supplies the existing district heating grid. It is planned to extend the facilities and to use surplus heat in the summer for wood drying processes.

§ 5.4.2 Demography

The community of Wolfhagen has shown a mostly positive population development until the early 2000s. With the closure of the military site in 2006, 530 persons left Wolfhagen within one year, resulting in a total loss of 3.5 % of the population in 2009 compared to 1996. The villages are more affected by migration than the central town. Over the past years only two of the villages show a slightly positive development in population (Figure 5.9).

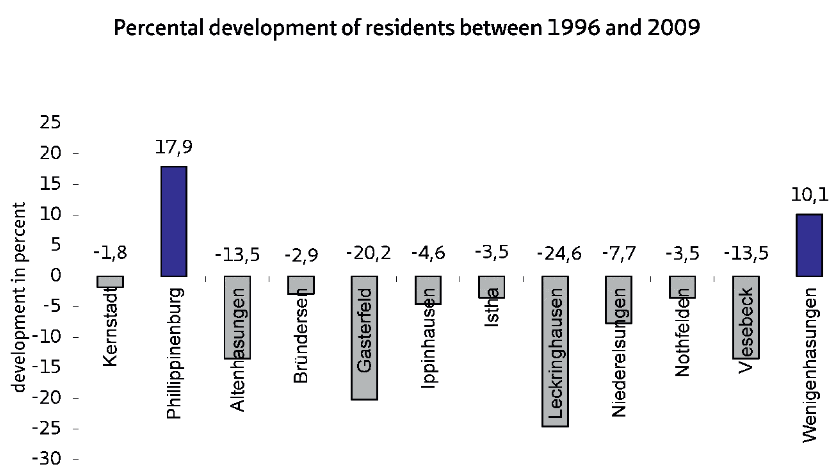


FIGURE 5.9 Development of residents in the districts 1996 to 2009 (Bergholter and Ettinger-Brinckmann 2010).

In Wolfhagen the signs of the demographic development continuously become more visible, especially in the town centre. Mostly little stores and shops are affected by the demographic and economic development resulting in increasing vacancies.

In the regional plan for the area of Nordhessen a total population of 13,040 inhabitants is predicted for Wolfhagen for the year 2020. This is a reduction of 5.5 % compared to the current numbers. Even when this is only a forecasting of present trends that can still change slightly in the course of future development, expectations are clearly towards a significant and continuous decline in the total population. This is mainly because the mortality rate cannot be compensated by the present moving-in rates. The demographic change and the expected age-structure will influence the population and consequently also the urban development strategies significantly and is of major importance for the energy transition process. At the same time the population becomes older. For 2030 the statistical office of Hessen anticipates a significant shift towards older age groups for Wolfhagen (Figure 5.10).

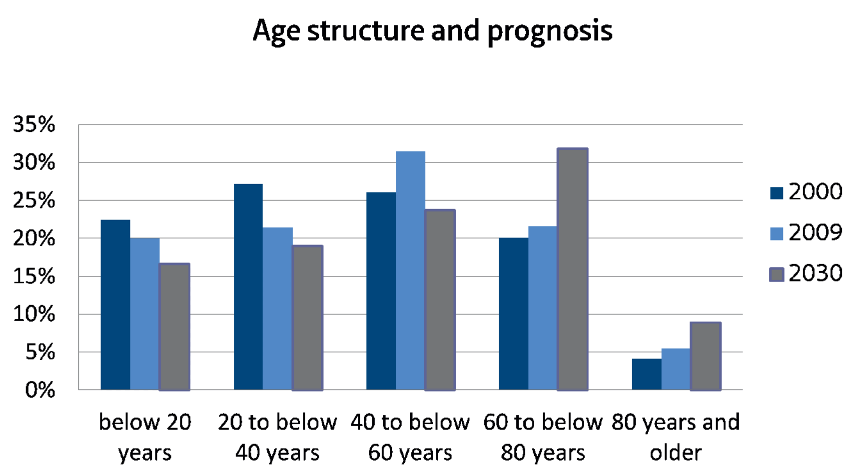


FIGURE 5.10 Development of age groups for the community of Wolfhagen (source: HessenAgentur 2011)

The prognosis for Wolfhagen is still slightly better than for the surrounding communities, which results mainly from the good infrastructure and the quick accessibility of Kassel by regional trains. This leads to a rather stable migration situation without severe losses towards the higher order cities and neighbouring communities.

The Bertelsmann Stiftung, a social development foundation, depicts general recommendations for communities as Wolfhagen in their demography report (Bertelsmann Stiftung 2005). The mayor challenge is seen in the adaptation of the social and technical infrastructure to the future demand under the preconditions of the demographic and economic developments. An essential problem might be a growing need for social transfer contributions to be handled by the public body and increasing economic problems of the public households. The authors of the study recommend the support of local initiatives and local potentials as key success factor. On a more detailed level the authors of a conceptual study Bergholter & Ettinger-Brinckmann (2010) analysed strengths and weaknesses and development potentials for the active centres programme. They emphasise the options for a better profile in the sectors tourism, education and renewable energies. A study of the industry and trade association Kassel draws similar conclusions (Aring *et al.* 2010). The focus on an energy transition process is an important step for the strengthening of the community of Wolfhagen and is appreciated and supported by local politics and enterprises.

§ 5.4.3 Economic Development

As middle-order centre in the rural suburban area of Kassel, Wolfhagen is mainly a residential location and a commuter town. The proximity to Kassel is positive for the local community because local industry can access the research and development potential of the University of Kassel and Wolfhagen can benefit from the larger and more diverse job market there. The development of the jobs subject to social insurance contribution at the location Wolfhagen has developed fairly positive in the past years. Between 1996 and 2000 there was a continuous incline that has continued after a short period of decline in 2001 and 2002. Since 2007 the number of employees is slightly falling and amounts to 3,200 persons. This is still 6 % above the level of 1995.

In comparison to other middle order centres, Wolfhagen has shown a good economic development over the past years. In 2008 49 % of all employees under social insurance contribution worked for the tertiary sector which represents the services trade, banking, education, health, transportation and public administration. The development of the number of employees in the economic sectors was characterised by an increase in the sector of *public and private services* as well as *trade, hospitality industry and transportation* and a decline in the sector *manufacturing industry* since the end of the 1990s. The sector *financing and letting, service provider enterprises* is evaluated since 2005 and has increased continuously ever since.

In Wolfhagen there are five commercial zones (Figure 5.11). The '*Hiddeser Feld*' in the north was developed and is operated in an intercommunal cooperation with the community Breuna. The industrial park *Hiddeser Feld* offers good conditions for new types of enterprises especially in the field *distribution and logistics*. The location of the REWE distribution centre and the spa producer VITAQUA represent these types of industry that would probably not have chosen the location in Wolfhagen a decade ago. Next to an older industrial park in the district of Niederelsungen there are two industrial parks in the central city. Additionally the sites of the former military site in the district Gasterfeld offer space for new industrial developments.

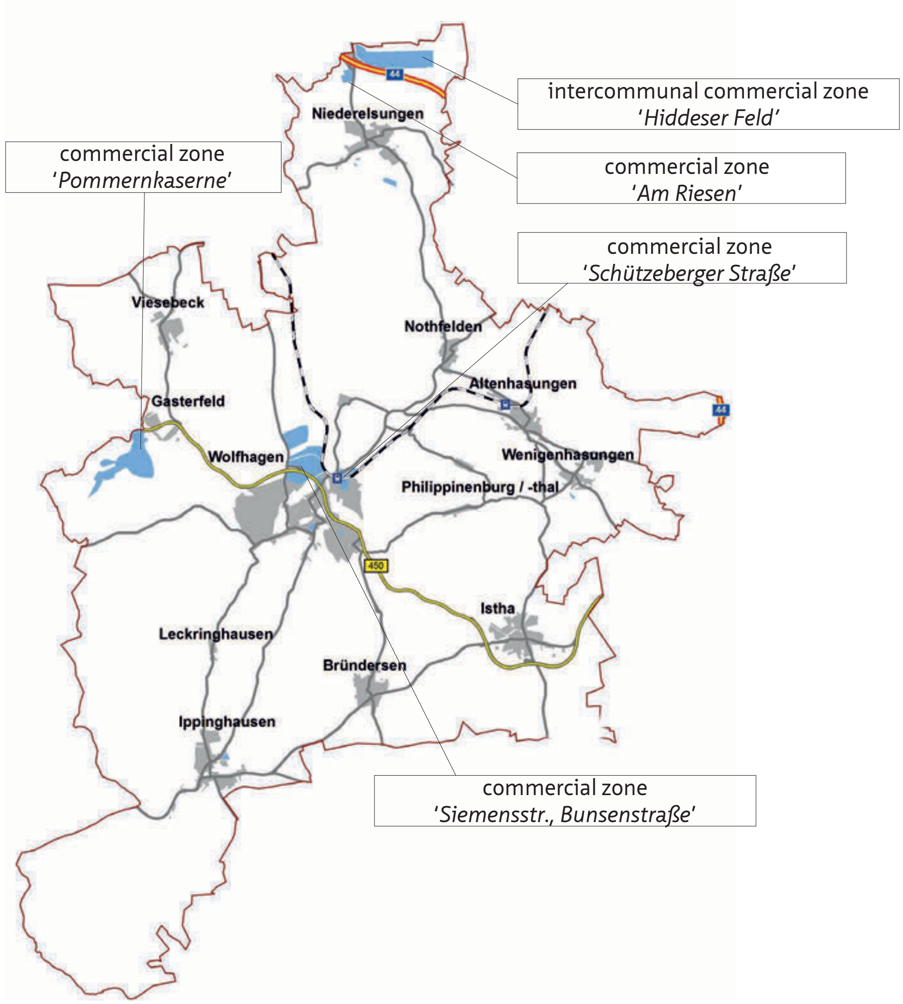


FIGURE 5.11 Location of the commercial zones

As middle order centre in a rural environment the city of Wolfhagen offers a broad mixture of stores, crafts, auto-shops, small-scale business and traditional medium-sized industry (e.g. Ackermann transportation technology, Königsdorf surface technology or Werner engine construction Ltd.). In addition small innovative companies are present, such as Kuntschar & Schlüter Ltd. in the field of CHP-plants or Energy Glass in the field of high insulation glasses and special purpose glazing.

§ 5.5 Status Quo Analysis of the Energy System

To start an energy transition process in the community, it is necessary to collect and monitor central data in a status quo analysis. In large cities this is usually done by the energy commissioner or the department for the environment. Because of its size there are no such institutions in the community of Wolfhagen, nor at the utilities or the local energy agency. All energy initiatives are managed by the town's planning department additionally to their core tasks. It is not surprising that the town of Wolfhagen has not yet implemented a consistent monitoring system of energy indicators so far, since this means a significant effort and deployment of staff. The status quo analysis for Wolfhagen for this thesis is done on the basis of available data from several sources and data collection in the context of the research project.

In the course of the research project the available data sources were systematically structured and gathered to get an overview of the situation. Despite these efforts there are still data gaps since neither the city of Wolfhagen nor the town utility company or the energy agency monitor their data in a systematic manner. The past development of energy demand and CO_2-emissions of the city of Wolfhagen can hardly be quantified on the basis of existing data. The city of Wolfhagen has supported a number of local initiatives for energy-saving in private households and has given some funding for this. The impact or total utilisation of the programmes was not monitored due to a lack of tools, staff and know-how. For instance there are no statistics on the impact of the existing communal funding programmes. Some information is available at ENERGIE 2000 e.V., the local energy agency, in the form of consultancy protocols, but the majority of measures were not monitored in the course of on-going work.

The status quo analysis had to be based on statistical meta-data, available on regional, state or national scale. The data was adapted to the Wolfhagen system boundary to estimate the status-quo and the developments over the past decades. Regarding the size of the community, it can be assumed that this is a rather typical situation, because there are no common and mandatory procedural standards for the monitoring of communal energy efficiency and implemented measures for German communities.

Evaluation reports on the effects of subsidy and public funding effects are published regularly by the Federal Funding Bank KfW. Their reports are used to estimate effects of funded refurbishment measures (Clausnitzer *et al.* 2011; Diefenbach *et al.* 2011; Kuckshinrichs *et al.* 2011). In Wolfhagen the collection and evaluation of energy indicators in the past depended on the personal commitment of individual employees in the planning department, who collected data next to their core tasks.

§ 5.5.1 System Boundary

The city of Wolfhagen is integrated in a system of regional and inter-regional energy supply structures. Electricity, fossil and renewable fuels are as well imported as exported over the community boundaries. For the energy transition process the geographic communal boundaries are taken as system boundaries. This includes the town of Wolfhagen and the eleven districts and their vicinities. The areal definition of the balancing boundaries has advantages and disadvantages. On the one hand the municipal territory is clearly defined. Typical demand indicators such as the energy demand of buildings or solar potentials can be regionally defined and represented in the balance. On the other hand the allocation of supply structures is more problematic with a fixed geographic system boundary, because they are organised in an inter-regional structure. That is why the number of customers supplied by the local utilities within the Wolfhagen network differs from the number of customers supplied by the utilities of Wolfhagen in total. Customers of the Wolfhagen utilities do not necessarily need to live in the municipality. This sometimes makes a clear allocation of the available data to the community difficult. Similar problems occur in the sectors transportation and biomass potentials. The energy demand for the transportation sector can only be estimated within the system boundaries because of unavailable data.

While in other projects and indicator systems there is often a reference based on the number of inhabitants, the geographical reference has clear advantages for the planning decision support tools and scenario studies. The more precise the geographical correlations and interrelations from the monitoring system can be displayed the better hot-spots of development can be identified. Energy system developments usually have a direct relationship to the geographic location of the demand and supply objects.

For a geographical overview, data from different levels and sources was collected to get a holistic overview of the energy systems. All data was collected and adapted to match the requirements of the GIS. Wherever no local data was accessible, the statistical data of the smallest available reference (usually communal statistics: Hessisches Statistisches Landesamt) and the available scientific publications were used. The data for the scenarios is given in chapters six to eight.

§ 5.5.2 Energy transition potentials and strategies

The preliminary energy and CO_2 balance so far only represents a section of the total picture for the energy system of Wolfhagen. In the context of this thesis only the energy demands of the private households were considered. As well the transportation sector was left out of the analysis.

Because of the high absolute energy demand the largest saving potentials lie in higher energy efficiencies in the building sector. This will be the core interest and focus of the scenarios outlined in chapter seven. To reach the goal of one hundred per cent renewable energy supply for the total energy system the community can follow different development visions. Energy efficiency in all consumption sectors is the necessary precondition to reach the goals from the demand side. This strategy involves the most individual decision-makers as consumers and home owners. A second strategy can be the rapid increase of local renewable energy production. As a rural community with large agricultural spaces and forests this is definitely a promising option and has been followed already for the past decades with quite some success. A third road-map scenario integrates both energy efficiency and renewable energy production strategies and combines them into a 'smart' solution with future-oriented technologies. This is probably the most far-reaching scenario regarding the necessary technology shifts. The results of this thesis are meant to initiate and support strategic discussions on the best development path.

§ 5.6 Conclusions

The analysis of the status quo situation in the case study of Wolfhagen reveals a number of strengths and weaknesses regarding the choice as a field study and research community for new planning approaches and tools in energy transition processes. First of all it has shown that there are numerous actors and interest groups that have to commit themselves to some extent to the goals and strategies of the transition process. Communication and illustration of the energy system is a central outcome the tool will have to deliver. The interests of the different stakeholder groups may conflict at some point, as the existing conflict about the planned wind energy park has already shown. It will be necessary to limit the impacts of these conflicts and not to let them gain dominance in the overall transition process.

From the analysis of the Wolfhagen status quo it becomes clear that there is no deficit in project initiatives and ideas. Numerous residents are motivated, interested and active in energy projects. Entrepreneurs and stakeholders take some action and start in their own 'front yard'. The flip side of the coin is that at the moment there is no place where all these initiatives converge. There is no real overview at the moment on what is all going on in energy issues in the community. The local authorities do not have the personnel capacities nor do they have the necessary overview to moderate and structure all the on-going projects. So far there has not been a central documentation or reporting scheme to follow-up on everything that is being planned and implemented. Consequently the initiatives have to succeed mostly on their own. They have to rely on their promoters' networks and experiences. Synergies between different approaches and targets remain unused, because the platform for information and communication under a superior strategy is missing.

To set up a process and to discuss and an overall strategy is a core task of the communal authorities and the elected councillors in the communal parliament. A planning and communication support tool as outlined in this thesis can support them in this new task. Since the elected councillors are politicians and usually nor energy experts the existence of a realistic energy model of the community can help to understand and identify correlations and potential conflicts. Secondly, the tool allows creating scenarios. The '*what happens if*..' question can help to identify real options and develop ideas on possibilities and technical limits. The research work in Wolfhagen has shown that stakeholders who do not feel competent in the technological or environmental details, risk to either follow dominant positions of interest groups or tend to withdraw from the decision making process. The tool should therefore supply basic and necessary facts and relationships between different sectors.

Last but not least the question of transparency and communication has shown to be a critical issue in the Wolfhagen community. Communities of the size of Wolfhagen commonly still possess a vital communal communication structure which is not necessarily media bound. The talk of the town is often quick and hardly ever correct in technical or procedural terms. A complex issue such as an energy transition process is not easily explained and described as a full picture. Since communication is always done on site, between neighbours and political stakeholders, the tool can facilitate and complement individual knowledge and supply information with a targeted and local scope.

Over the status quo analysis in Wolfhagen the necessary outline of the tool to be developed within this work became clearer in its demands. From the experiences a two level approach is proposed: on a professional level data sources have to be maintained, improved and updated. The scenario models have to be allocated also on this level. The users in scope are the employees of the planning departments and communal consultancy experts. Technical details and synergy effects are important bits of information for the strategic target on this level. A second layer of information should address public interest and implement the communication strategy of the transition process. The merging of both target groups via one platform should make the handling and updating of data feasible for small communities (Figure 5.12).

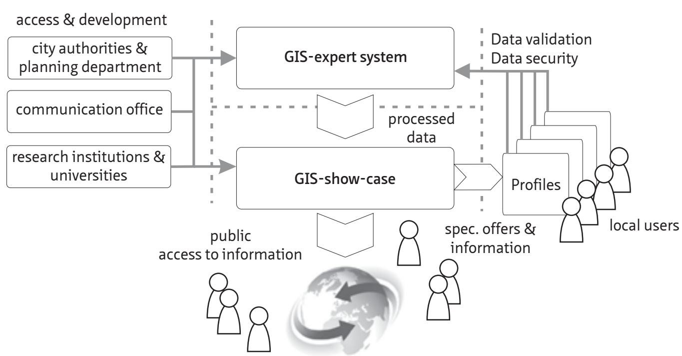


FIGURE 5.12 For a long-term implementation the tool will show a two level access to the GIS data core.

The results of the case study analysis serve as background information for the interpretation of the scenario application in chapter eight. Furthermore it is important to understand the town development in energy terms to evaluate options for the future. The chapter gave an overview on the available data situation which will be further elaborated and specified in the following chapters six to eight.

6 Technology Assessment and Modules

"If nature had been comforatble, mankind would have never invented architechture."
Oscar Wilde (1854 – 1900)

§ 6.1 Introduction

Chapters six, seven and eight describe the central modules that influence urban energy systems. This can be regarded the collection of data and information to fill the scenarios in chapter nine and perform the application in chapter ten. The two research questions for these chapters are: What default energy system components can represent the communal energy system with sufficient accuracy? And, for the specific sections: Is there a sufficient local data availability to create a specific model of the energy system? For better readability the three principle columns of urban energy systems are covered in separate chapters. Chapter six covers questions of urban settlement typology design and mainly issues of the demand side. Chapter seven is giving an overview on the renewable energy potentials and their exploitation. Chapter eight is concerned with technologies for cross-sectoral integration of systems. The technologies covered represent relevant energy related technologies and measures that may be influenced by urban planning. This is an important precondition because I assume that the central target group for this decision support is the community and associated stakeholders. The data structure of all three chapters is divided in two parts. A summary of general data and assessment procedures serves as the default data framework. This means that whenever there is no specific local data available the default data can be used to fill the gaps. Local data can make the modelling more specific and meaningful for the transition scenarios. In addition to the general data, specifications for the case study are given. Assessment methods and deviations from the default values are specified to explain necessities for specific data acquisition. For the scenarios it is important to give information about the development potentials of the different modules. These give the limiting rails between the scenarios may evolve over the scenario timeline. While in chapters six, seven and eight the data background is described, the development assumptions, interactions between developments and timelines are part of the scenario considerations in chapter nine.

§ 6.2 Methodology

The principal methodology for this chapter follows the idea to provide core input figures for the scenario model. To start a scenario discussion process there has to be a basic data framework. As already explained in chapter five, a GIS system is able to integrate different types of information as long as they have a geographic reference. This chapter provides basic data from literature and previous studies as far as available and useful for the scenario model base-case. The methodology implies that there is some basic information available on local conditions as well which makes the default data more specific. The figures provided in this chapter add the quantitative aspects to the qualitative case study analysis of chapter four. There are many technologies and system solutions available in the field of energy efficiency and renewable energy production. There are numerous energy system technologies for system optimisation as well. Therefore the first important step is to identify the most relevant, widespread and 'state-of-the-art' technologies for the community scale in focus. The selection of technologies and system solutions follows the results of the TRANSEP-DGO project (see toolkit by Kortman 2012) and the project outline for Wolfhagen for the BMBF Wettbewerb (Sager *et al.* 2010). The data for the general section comes from literature, scientific reports and official statistics. For good comparability with the case study data, the general data mostly refers to German conditions. The general data is mostly non-geographic. To achieve compliance with the GIS system a geographic reference has to be added to the non-geographic data if it is used in the model. The case study data comes from community statistics, on-site data collection, expert interviews and a household inquiry done in 2010. There are also sources with and without geographic reference available on local level. Basically the same rules for referencing data apply to the specific data as for the general data. To fill in gaps and to create a more specific picture some simple energy and exergy calculations provide data on the case study level.

§ 6.3 Fields of action for urban energy transition

The aim of the chapter is not a complete compendium of data for all available energy technologies. The idea is to give a data collection on the most important aspects of potentials and restrictions of available 'state-of-the-art' measures and technologies. The structure of the chapter is similar to the scenario 'stories' of chapter nine (Figure 6.1).

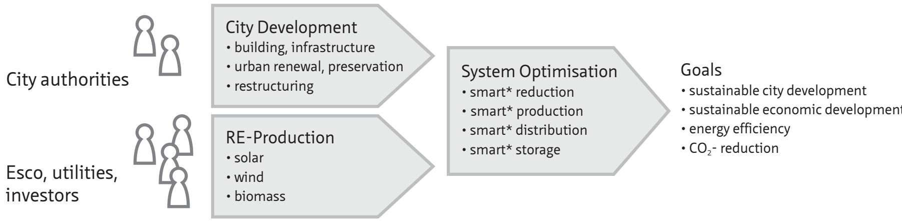


FIGURE 6.1 Fields of activity of the stakeholders in the urban energy transition process.

Since decision-makers of the city planning authorities are the target group for the implementation, I start from their core tasks of urban development. These include building and infrastructure projects as well as refurbishment and restructuring of the existing building stock. The long-term goal of urban development is sustainable development of the city's population, infrastructure and social and cultural life in general. Urban development and restructuring is often a starting point for transition projects and can have great impact on energy efficiency and savings. This field of action correlates to the targets and measures in the efficiency scenario which is focussing on savings measures primarily.

Secondly, the most relevant renewable energy production technologies are described. These often are starting points for transition processes as well, although the initiative often comes from ESCOs, local utilities or private investors. The local potentials of renewable energies represent the options on the supply-side of the energy balance. The issues are central targets in the renewable energies scenario which is striving for a maximum exploitation of renewable energy resources. This is not a core task for urban task for communal decision-makers but city authorities can influence, steer and manage the development to some extent. Already local governments are concerned with development questions of large-scale renewable energy plants and the moderation of public discussion.

One step further goes the fourth scenario, in which an improved local matching of the demand and the supply side is addressed. For communal decision-makers as well as for local utilities these 'connection' and 'interaction' aspects often are a new terrain. Nevertheless both on local as well as on national scale, the largest innovation and efficiency potentials for the future are seen in this field.

§ 6.4 Data framework for the settlement typology design

The city's existing urban structures have a big influence on the structural development of infrastructure, the organisation of property use, and long-term development dynamics. The strategies for new developments, refurbishment programs and the demolition of infrastructure directly influence the energy demand structure of the community. The first step for modelling the energy system of a community is to create a model of the built environment. In this case for residential buildings in the case study community. The analysis of the existing settlement and building structures follows the steps in Figure 6.2. Step by step the generic data, line 'A', can be validated and specified by more specific local data sets, line 'B'.

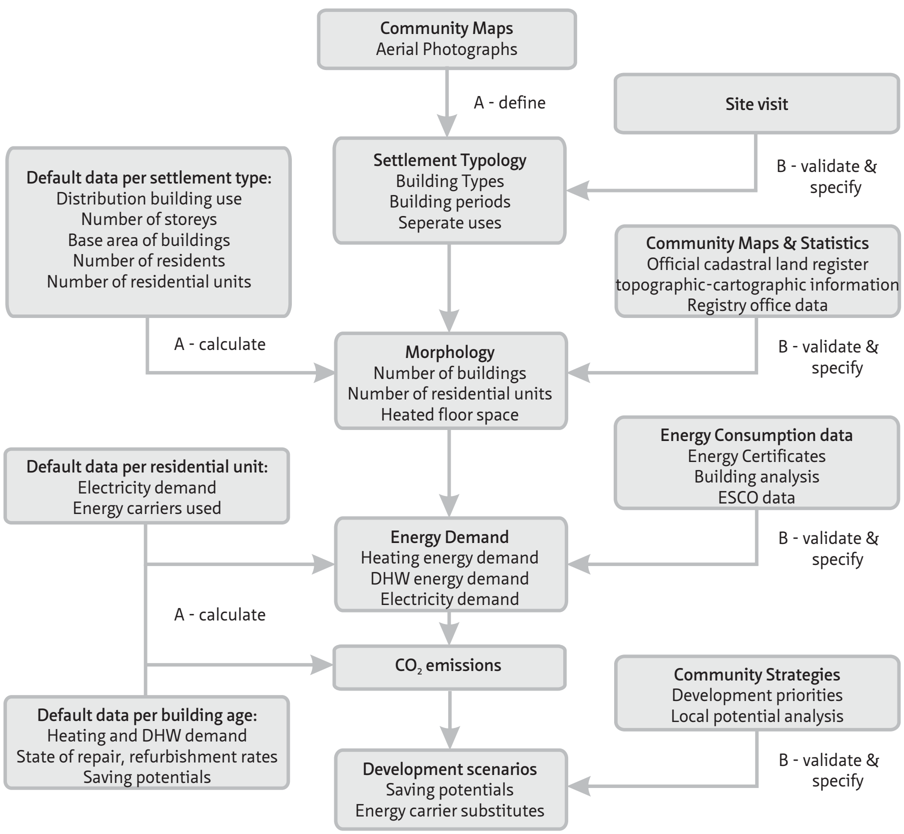


FIGURE 6.2 Flowchart of default data framework with additional local specifications

The urban morphology affects the overall energy balance of a community in several ways. The correlation between energy consumption and city structure are not easily measurable and not many interactions have yet been scientifically described. Most morphology studies focus on large cities and assume full occupancy of the analysed structures (Salat 2009, Salat *et al*. 2011). The correlation between urban morphology and transportation energy use has been described in several scientific publications (e.g. Newman & Kenworthy 1991). There are also countless studies on the effects of building design and urban patterns on energy efficiency and solar potentials, for instance by Everding & Kloos (2007), Bonhomme *et al*. (2011) and Kürschner *et al*. (2011). This knowledge can lead to optimised urban structures and buildings wherever new developments are made. Urban developments of today show that the optimal solution can be realised to full extent only exceptionally. A detailed analysis of energy-related aspects in existing urban morphology was done by the University of Darmstadt in the UrbanReNet project (Hegger *et al*. 2012). Based on German urban morphology typologies (Roth *et al*. 1980, IWU 2003) the study analysed central energy parameters for energy demands and potentials. Since the study is based on existing structures and elaborates the potentials within the existing structures and preconditions, it is a valuable default data source to work with.

With the focus on medium- and small-scale communities the primary focus is commonly not on high-density inner city block structures but on more or less sprawled one- to five-storey buildings. From a common interpretation of the relationship between urban density and energy consumption these are rather unfavourable conditions because dense urban structures are regarded to be more energy efficient than low-density structures (Salat & Nowacki 2011). Dense urban structures in small- and medium-sized communities are usually historic town centres, with many buildings of high heritage values but rather low energy efficiency. The conflict between the preservation of the old structures and buildings and present-day building standards can be a severe barrier for energy transition projects that aim at urban restructuring.

On the other hand old centres are surrounded by area expansions of single-family houses with low densities and few common facilities and services. Starting from the post-war building boom, small- and medium-sized communities concentrated mostly on extending their settlement and industrial areas around the core centres of the towns. Competing against neighbouring communities for young families and tax income, belts and clusters of mostly single-family houses were developed around the old town centres. Growth was the central trend for most communities since the economic boom in the 1960s. Only lately this trend has slowed down and then inversed for many communities away from the remaining boom towns. The demographic challenges they face bring an over-aging and declining population and hit most communal planners rather unprepared. So far not many strategies and tools to approach the upcoming problems are available. The ancient town centres suffer from growing vacancies and the moving away of trade and commerce. This development is often a first visible result of demographic change. Young families are moving towards the fringes, the elderly remain in their much too large old buildings in the centres. For communal planners this is a major development challenge also in the scope of energy transition. For small- and medium-sized communities energy transition projects have to focus also on future-oriented solutions for dense town and village centres with their large share of historic buildings and heritage protected ensembles and to reduce urban sprawl by reducing new settlement developments and rather concentrate on restructuring and densification of the already developed areas.

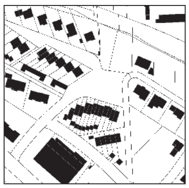
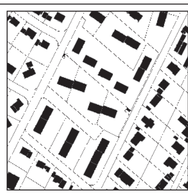
§ 6.5 Urban settlement and morphology typologies

In this section the data regarding the built environment is collected and analysed according to the question what kind of data can be useful for the simplified GIS model. High density urban structures commonly have lower specific heating energy demands than sprawled districts with single-family dwellings. This is because of the dominance of multifamily-buildings and block structures in city and town centres. Additionally the average size of apartments is smaller than in single-family dwellings. These morphologic typologies can be found not only in the centres of large cities and towns but also in many medium-sized towns built on medieval city layouts with many historic buildings. Because of the limited space within city walls buildings were larger and usually built for more than one family. Because of the historic constructions the options for efficiency refurbishments are limited by structure and building physical constraints. The extra effort that has to be taken to improve these buildings in energy efficiency is costly and often too high a burden for inhabitants and owners. For the model analysis it has to be noted that a cross evaluation of resident structures and building typology is necessary. If the actual number of residents deviates from the number assumed in the settlement typology, the mistake in all energy consumption figures based on residents and households will be higher.

§ 6.5.1 Section A: generic data on urban morphology parameters

A basic study on the urban morphology characteristics in Germany was published by Roth *et al.* (1980), based on typical figure-ground diagrams of German settlement structures. From them he derived a set of energy characteristics for nine representative settlement types. This study has frequently been used and extended to obtain standardised data for energy supply options, for instance by Lutsch *et al.* (2004b) and

BBSR (2011). Both Roth *et al*. and Lutsch *et al*. put their specific focus on the potential for district heating systems for city typologies. Since conventional district heating systems require a certain density of building structures and energy demand, the primary focus of these studies was on the dense settlement structures and larger cities (> 20,000 inhabitants) (Lutsch *et al*. 2004b). The study of the University of Technology Darmstadt extended the data of these sources with primary focus on renewable energy potentials from solar, geothermal and biomass sources. The figures base on average hectare values. The study comes up with 13 typologies, including two typologies dominated by office, trade and other service buildings and three typologies of public open spaces. Since these studies always aim to cover all existing city structures, only a subset of typologies is relevant for the case study of this thesis. The relevant typologies are summarised in Figure 6.3. Additional data on the residential floor space can be found in Table 6.1.

Isometric Settlement Type	Figure Ground Diagram	Density[1]	Buildings[1]
Single and multifamily settlements of low density ST 1[2] / EST 1[3]		Buildings [per ha]: 11 - **14** - 19 Number of residential units [per ha]: 12 - **21** - 49 Number of residents [per ha]: 24 - **42** - 96	Building type distribution: $^2/_3$ single family - $^1/_3$ small multi family Building use: 100 % residential Number of full storeys: 1.5
Village centres and single-family settlements of high density ST 2 / EST 6		Buildings [per ha]: 30 - **68** - 125 Number of residential units [per ha]: 35 - **86** - 160 Number of residents [per ha]: 69 - **170** - 316	Building type distribution: $^2/_3$ single family - $^1/_3$ small multi family Building use: 100 % residential Number of full storeys: 2.0
Terraced houses ST 3 / EST 2		Buildings [per ha]: 22 - **35** - 51 Number of residential units [per ha]: 22 - **35** - 51 Number of residents [per ha]: 56 - **90** - 129	Building type distribution: 100 % single family Building use: 100 % residential Number of full storeys: 1.5
Mid-rise housing slabs ST 4 / EST 3		Buildings [per ha]: 11 - **17** - 27 Number of residential units [per ha]: 61 - **104** - 162 Number of residents [per ha]: 111 - **188** - 292	Building type distribution: 100 % small multi family Building use: 100 % residential Number of full storeys: 4.0
Medieval town centre ST 8 / EST 7		Buildings [per ha]: 48 - **114** - 154 Number of residential units [per ha]: 92 - **260** - 368 Number of residents [per ha]: 171 - **481** - 678	Building type distribution: 45 % single family - 55 % small multi Building use: 100 % residential Number of full storeys: 3.5
Industry, Trade, Services ST 9 / EST 10		individual analysis necessary[4]	

[1] All data fromHegger *et al.* 2012. The figures give the minimum, median and maximum values of the anlysed case studies
[2] Building typology in Roth *et al.* 1980
[3] Equivalent building typology in Hegger *et al.* 2012
[4] The authors of the study Hegger et al. 2012 suggest the approach of spatial approximations in the case of industrial, trade and service spaces. This is mainly because of the great diversity of uses within similar building types.

FIGURE 6.3 Excerpt from the settlement typology of (Roth et al. 1980) and (Hegger et al. 2012)

The cited data shows quite a variance in the density parameters. The data was derived from the analysis of existing typologies with a good representation of the German situation (Hegger *et al.* 2012). The values are given as minimum – median – maximum values for the analysed examples.

BUILDING TYPE	NUMBER OF RESIDENTIAL UNITS	RESIDENTIAL FLOOR SPACE PER UNIT [m²]
Single family house	1	127.2
Duplex family house	2	93.9
Small multi-family house	3-6	74.8

TABLE 6.1 Statistical values of residential floor space in the different building types (Hegger *et al.* 2012)

On this basis the morphology of the community can be characterised with important figures needed as default references of energy demand, for instance the total number of buildings, the number of residential units, the number of residents and the heated floor space. By correlating the settlement typology to the inhabitant structure a more differentiated settlement structure can be obtained. More detailed building structure data helps to specify the statistical values and to improve the outcome of the scenarios. This way the demand for using standardised typologies is reduced step by step. On the other hand a good approximation can be achieved with default data so the necessary data collection can be limited to a minimum. The validation and data collection is superseded by the need for continuous updating of the obtained data set. This is why it is so essential to achieve high acceptance and continuity in every work of the model. Within the databases it is important to track the data origins as soon as the default values are altered.

§ 6.5.2 Section B: specification of urban morphology

The data in Figure 6.3 is used to create the quantity structure of the residential buildings within the community. To come to a first rough approximation of structure, the community area has to be analysed according to settlement structures (Figure 6.4). Based on the default data a rough typology can be built on the basis of aerial photographs and cadastral maps.

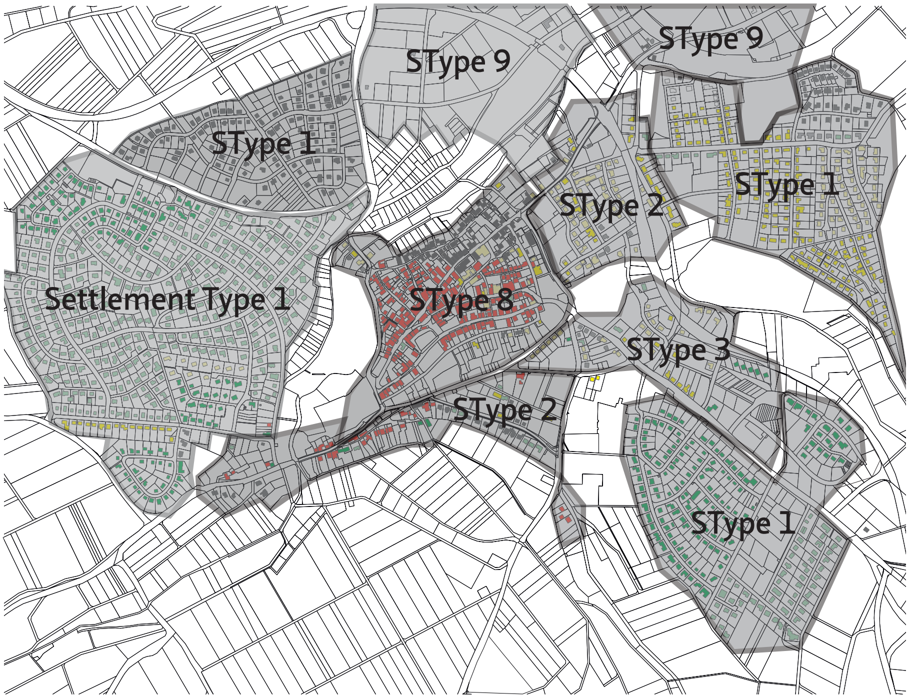


FIGURE 6.4 Structural settlement analysis by settlement types and spatial evaluation for the case study of Wolfhagen.

In order to verify the desk study an on-site validation is necessary. In order to verify morphology data it is very helpful to check the assumptions on-site. Especially in old rural towns and villages the impression of aerial photographs and cadastre maps can be misleading because of the sometimes large number of non-residential adjoining buildings (Figure 6.5). Often these buildings can be identified automatically from the registry in the official cadastre files, but often the entries in the cadastres are unclear or incomplete. Therefore an on-site visual inspection and verification of data is useful to correct the morphology model. In some small- and medium-sized communities vacant residential buildings may as well distort the automated results. In that case a close cooperation with the community authorities sometimes is fruitful to identify vacancies.

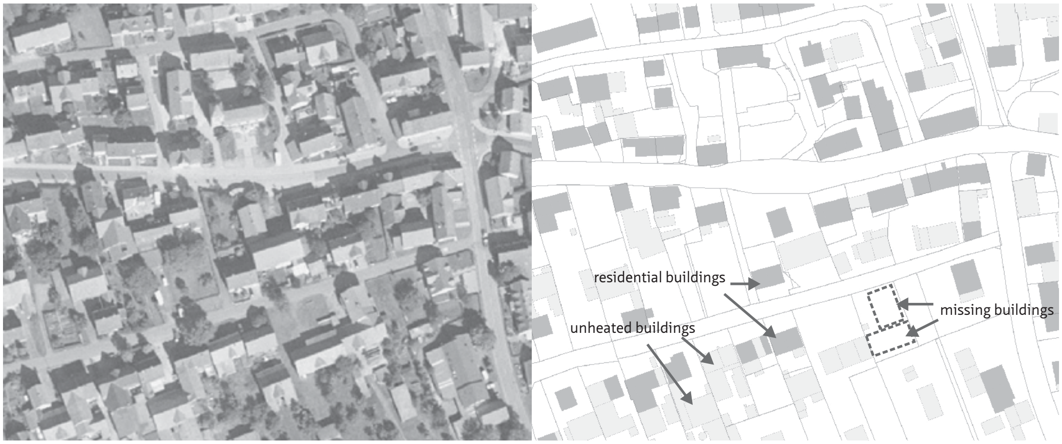


FIGURE 6.5 In the aerial photograph residential and non-residential buildings cannot be differentiated properly as the indication of non-residential buildings (light grey) on the map shows.

Partly automated procedures allow the allocation of building typologies over the entire community area. This can be done for instance to identify non-residential buildings that can be identified by ground floor size. These are unheated buildings such as garages or carports, garden houses or transformer substations. The typical ground floor size of single and double garages is between 13 m² and 51 m². If the minimum limit of ground floor size for main buildings is set at 45 m² the non-residential buildings can be identified with a good result in typical residential areas (Figure 6.6).

It can be assumed that despite the corrections the total heated floor space for the case study is probably too high. This is mainly because not all unheated adjacent buildings could be clearly identified by the on-site visit. Also there are many older buildings, which are not completely heated or where unheated building parts are not visible from the exterior appearance. Since cadastral data usually provide no clear definition of the building usage, for instance as residential building or unheated adjacent building, validation of the floor space is not possible without detailed on-site analyses. For the purpose of the scenarios the adapted typologies are considered precise enough to represent the community situation.

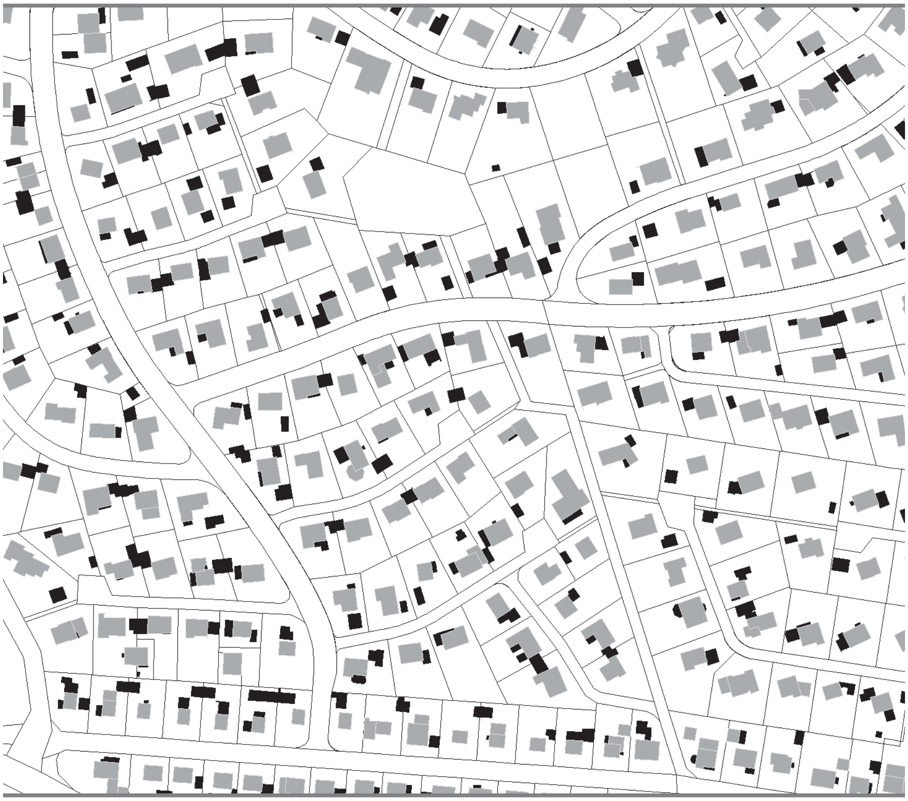


FIGURE 6.6 Automated analysis result to identify unheated buildings. All unheated buildings as garages and sheds are identified by size and taken out of the calculation (indicated in black on the map).

§ 6.6 Energy demand in households

To get to a demand-side profile, the heating and domestic hot water demands have to be estimated on the basis of the typologies. Since buildings within the settlement typologies are of different building ages, different energy demand values can be assumed because of changing energy requirements and preferred building materials. The construction period is concidered to be the most dominating factor for the assumption of the heating energy demand. In each building period a typical construction type was dominating and a specific requirement level in energy efficiency was mandatory for new buildings.

§ 6.6.1 Section A: Generic data on energy demand in households

The typology data source most citied in Germany is the building typology study by Diefenbach & Born (2007). Here typical building and envelope characteristics of the building periods were modelled and described. On this basis LEE (2009) calculated the reference values for the refurbishment qualities in the research project, which will be used as orientation values for the thesis with regard to heating energy demands (Table 6.2). For the first refurbishment level the entire envelope is renovated. For the second level the heating system is adjusted as well, and for the third level the envelope is renovated to better insulation level and the building energy supply system is supported by solar thermal collectors for domestic hot water production. The contribution of the solar collectors reduce the amount of conventional energy needed for hot water production and therefore reduce the overall energy demand, which is neglecting renewable heat input in German calculation regulations. The third level is meant as the 'passive-house-equivalent' for the existing building stock and the maximum efficiency that can be achieved for existing buildings. Even though the figures are artificial, studies show that these results may be reached with good planning and implementation (Stolte *et al.* 2012).

	BUILDING PERIOD	UNREFURBISHED CHARACTERISTICS	EFFICIENCY POTENTIALS (FINAL ENERGY)		
Single family buildings	before 1918		Level 1	Level 2	Level 3
		Heating energy demand [kWh/m²]: 255 Final energy demand [kWh/m²]: 332 Energy demand for DHW [kWh/m²]: 25	[kWh/m²] 121	[kWh/m²] 109	[kWh/m²] 61
	before 1918		Level 1	Level 2	Level 3
		Heating energy demand [kWh/m²]: 275 Final energy demand [kWh/m²]: 360 Energy demand for DHW [kWh/m²]: 25	[kWh/m²] 142	[kWh/m²] 126	[kWh/m²] 71
	1958-1968		Level 1	Level 2	Level 3
		Heating energy demand [kWh/m²]: 192 Final energy demand [kWh/m²]: 257 Energy demand for DHW [kWh/m²]: 25	[kWh/m²] 115	[kWh/m²] 103	[kWh/m²] 58
	1984-1994		Level 1	Level 2	Level 3
		Heating energy demand [kWh/m²]: 159 Final energy demand [kWh/m²]: 116 Energy demand for DHW [kWh/m²]: 25	[kWh/m²] 84	[kWh/m²] 78	[kWh/m²] 66
Multi family buildings	before 1918		Level 1	Level 2	Level 3
		Heating energy demand [kWh/m²]: 239 Final energy demand [kWh/m²]: 314 Energy demand for DHW [kWh/m²]: 25	[kWh/m²] 137	[kWh/m²] 122	[kWh/m²] 68
	1969-1978		Level 1	Level 2	Level 3
		Heating energy demand [kWh/m²]: 140 Final energy demand [kWh/m²]: 199 Energy demand for DHW [kWh/m²]: 25	[kWh/m²] 114	[kWh/m²] 101	[kWh/m²] 57

TABLE 6.2 Examples from the building typology with typical building types (after LEE Lehrstuhl für Energiesysteme und Energiewirtschaft and GEF Ingenieur AG Leimen 2009, own calculations)

For the case study a total of 28 typologies (single-family buildings, row houses and small multifamily houses) are embedded. For serial and partial refurbishments the energy reduction assumptions can be reduced according to the assumptions in the scenarios. There is no reliable information on the state of repair and refurbishment in the present-day building stock. Cischinsky & Diefenbach (2014) state that from their study on the situation in the state of Hessen a reliable data basis could not be constructed because of missing data. The information on refurbishment rates vary significantly in analysis reports on the German situation. The Federal Government assumes a yearly refurbishment rate of 1.3 % with declining tendency (BMWi 2007), the research cooperation FVEE assumes a refurbishment rate below 1 % (FVEE 2011) other sources assume more than 2 % (Friedrich *et al*. 2007). To make an assumption on past refurbishment activities the refurbishment rate of 0.8 % is assumed since the year 1990 to start with a partly refurbished building stock in 2010.

Regarding the refurbishments of buildings, there are rather long-term intervals assumed for renewal. Typical values for renewal cycles over a certain period of time can be found in IEMB (2006) and Bundesinstitut für Stadt (2011). The building construction is very long lasting and is hardly every changed substantially over the period of use. More often building elements such as windows or wall coverings and insulation layers are renewed. Heating systems and technical installations have even shorter statistical life-spans (Figure 6.7).

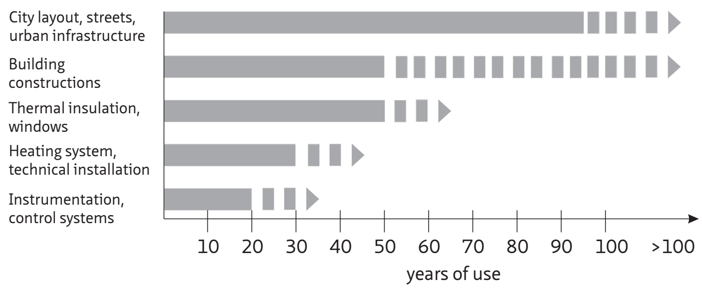


FIGURE 6.7 Technical life-spans of elements in urban and building structures

It should be noticed that in practice the refurbishment intervals are usually determined by occasions for renewal, damage or technical breakdown. The time-spans between the renewal occasions can be very different from object to object. As described in chapter nine for the scenarios it is assumed that buildings are up for refurbishment again after 30 years.

For an assumption on the CO_2-emissions caused by heating and domestic host water production the energy carrier used in the building is the most important factor. The German distribution of heating systems in 2010 is given in Figure 6.8. To make an assumption on the efficiency potentials for the decentral heating systems Kaiser (2011) gives a more detailed analysis on the distribution of the heating technologies for fossil fuels (Figure 6.9).

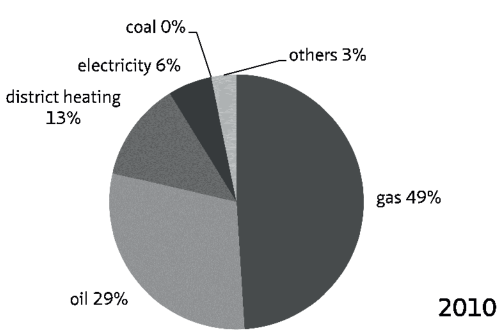


FIGURE 6.8 Heating structure of the residential building stock in Germany (source: Statista.com 2015)

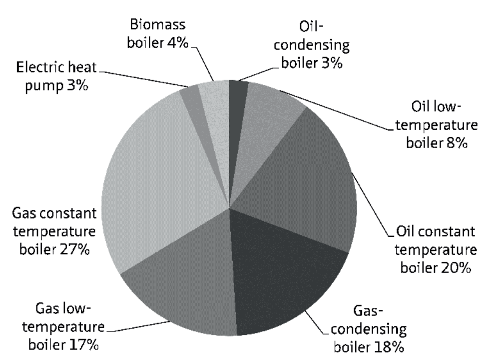


FIGURE 6.9 Distribution of decentral heating systems in Germany

The efficiencies of heating systems of different periods and system configurations can be found in Loga & Imkeller-Benjes (1997). Assumptions on future developments in efficiency were made by Matthes *et al*. (2013). A summary is given in Table 6.3. The annual efficiency of a boiler is the ratio between the heating energy produced and the energy carrier demand. It is based on the net caloric value. Since the efficiencies of boilers especially constant temperature boilers, depend on the operation time and system configuration, the values are all based on single-family buildings and an average operation design.

TYPE OF BOILER	EXISTING (UNTIL 1978)	2009	2030
Oil-condensing boiler	0.91	0.928	0.928
Oil low-temperature boiler	0.90	0.923	0.923
Oil constant temperature boiler	0.78	0.81	-
Gas-condensing boiler	0.98	0.98	0.991
Gas low-temperature boiler	0.92	0.925	92.5
Gas constant tempera-ture boiler	0.78	0.83	-
Electric heat pump	-	3	3
Biomass boiler	0.71	0.77	0.86

TABLE 6.3 Boiler efficiencies for single-family buildings (source:Loga & Imkeller-Benjes 1997, Matthes *et al.* 2013)

The electrical energy consumption is commonly assumed by household profiles. With the total number of inhabitants the household profiles in cities differ somewhat. This means that small- and medium-sized communities accommodate more households with a greater number of persons than in larger cities (Figure 6.10). This has to be taken into account for the assumptions on the electricity demand.

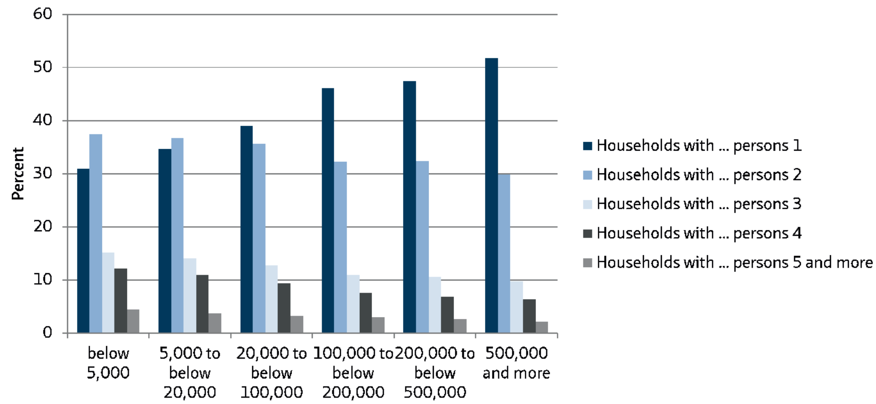


FIGURE 6.10 Distribution of households by different community sizes (source: www.bib-demografie.de)

Hegger *et al.* (2012) give the corresponding electricity consumption data in Table 6.4.

ELECTRICITY DEMAND PER YEAR				
1 Person	2 Persons	3 Persons	4 Persons	>5 Persons
1,733	2,930	3,749	4,527	5,110

TABLE 6.4 Statistical values of electricity demand per household as average values for households which do not use electricity for heating or hot water production (Hegger *et al.* 2012)

§ 6.6.2 Section B: specifications on energy demands in households

From the generic data presented in section 6.4.1 a more specific view on the case study situation is necessary. While the space typology for detached single-family houses matches well with the national building typology presented above, there are significant differences for the small multi-family buildings, which show smaller sizes than the national typology. The reason for this is that there are hardly any multi-family buildings in Wolfhagen. The local housing cooperation, the '*Nassauische Heimstätte Wohnstadt*', has 247 rental apartments in Wolfhagen in their portfolio. The local commercial landlords own mostly only few apartments or are private landlords. The focus of the refurbishments is therefore laid upon the private owners and users of residential buildings, since these represent the largest group of residents in Wolfhagen. Resulting from the data collection on the building typology and the heating demands an overview map on the building typology in the community can be created on which the heating energy demand of the case study is based (Figure 6.11).

FIGURE 6.11 Application of the settlement and building typology approach for the case study

In heterogeneous town and village structures it is often difficult to assign building periods to entire clusters, since the neighbouring building sometimes come from entirely different building periods. Starting with default data with a rough estimation of building ages, more differentiated data on different buildings and their energy quality can improve the data continuously.

For the town of Wolfhagen and the town districts a building typology was developed, which included the building ages, number of stories and types of use. The data sources were the developments plans and a simplified on-site data-collection. The central town of Wolfhagen was analysed in detail in the master thesis of Dawit Negash (Negash 2008). The emphasis in this work was laid upon residential buildings and communal buildings (Figure 6.12 and 6.13).

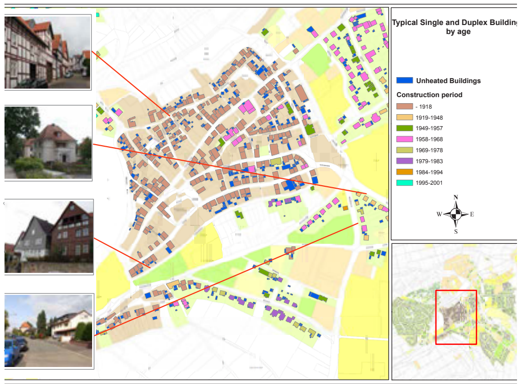


FIGURE 6.12 Building ages typology for the central town of Wolfhagen (from Negash 2008)

FIGURE 6.13 Building ages typology for the development area of Wolfhagen (from Negash 2008)

According to the distribution of building spaces and the building typology there is an approximate energy demand of 160,760 MWh for heating purposes for the 3,500 residential buildings in Wolfhagen per year. This leads to CO_2-emissions of approximately 42,736 tons per year.

Wolfhagen is not supplied with natural gas pipelines area-wide. Merely the central town and the military facility in Gasterfeld have a grid for natural gas. The total demand of natural gas rose from 52 million m^3 in the year 1998 to 57.5 million m^3 in the year 2007. For 2007 this represents a total amount of energy of 575,000 MWh primary energy. Because this includes the commercial and industrial consumers the portion of private households cannot be differentiated.

The household inquiry resulted in a distribution of energy carriers with more than 50 % oil and only 22 % gas (natural and liquid gas). Biomass heating is also very popular in Wolfhagen, whereas electricity for heating and heat pumps are not widespread (Figure 6.14). These specifications are used for the scenarios as well. No specific data on the distribution of the different heating systems was available, because it was not possible to establish cooperation with the local chimney sweepers in this issue. Therefore the assumptions from 6.4.1 are used.

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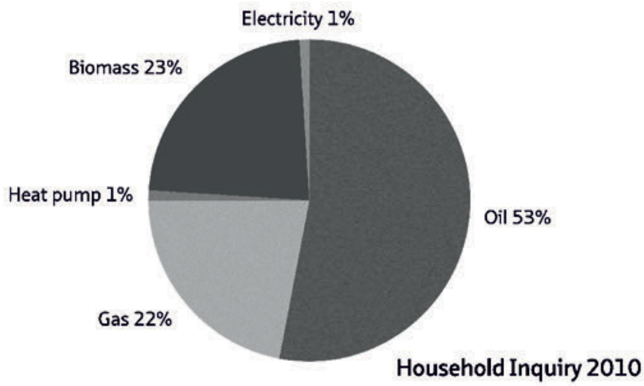

FIGURE 6.14 Distribution of energy carriers in the households of the case study

Neither in the town of Wolfhagen nor in the districts and villages around it significant local heating networks exist. Only the former military facilities in Gasterfeld were supplied by a widespread heat grid. There the energy supply is planned with heat and power units on the basis of wood gas to replace the former oil heating. The thermal power of each unit is 240 kWth with an electrical power of 125 kWel. One of these CHP plants is already in operation and produces electricity and heat for the adjacent school buildings.

There are two smaller local heat grids on the basis of natural gas CHPs in the residential area of '*Teichberg*' and at the elderly home in the '*Karlstraße*'. All three plants are operated by the utilities. Another small heat grid, currently supplied by an oil burner, supplies the restaurant '*Haus des Gastes*' in Ippinghausen, the fire department and the kindergarten. In total 670 MWh of electricity from CHP plants was fed into the local net in the year 2009.

A specific evaluation of the household structure is not available on community level. On the basis of the default data the household structure was assumed according to Table 6.5 resulting in a default electricity consumption of approximately 17 GWh per year. The actual electricity delivered to the households in Wolfhagen by the utilities is approximately 20 GWh per year. For the scenarios the actual values are used even though a detailed distribution to households cannot be done.

NUMBER OF HOUSEHOLDS				
1 Person	2 Persons	3 Persons	4 Persons	>5 Persons
1,954	2,196	818	685	217

TABLE 6.5 Calculated household structure for Wolfhagen

Within the community boundaries there only is a medium-voltage power grid; no high-voltage distribution lines cross the communal area. The Wolfhagen utilities supply within the communal area water and electricity for private households and commercial customers. The total electricity distribution is about 76 GWh per year. This includes one large-scale consumer, VITAQUA a drinking water company, which alone has a yearly electricity consumption of approximately 27 GWh. Since autumn 2007 the Wolfhagen utilities buy the electricity for their household customers from certified 100 % water power plants. The CO_2 emissions resulting from the electricity consumption contain the renewable portion (own production and purchased water power) for the private consumption and the commercial and industrial electricity from conventional production (German Electricity Mix). In total there are emissions of almost 31,000 tons per year from the electricity demand.

§ 6.7 Conclusions

The first step of building a representative model of communal energy systems is focussed on the demand side. The building structures and the different sectors of urban energy consumption have to be put into a representative model. The review of literature showed that there is default data available from many studies. It has to be stated though that the focus of most studies has been on city structures and mostly urban environments. For small- and medium-sized communities there are deviations because of different building and settlement structures. Compared to the literature data it can be stated that there is a tendency towards larger floor spaces, less inhabitants per hectare and more non-residential unheated buildings in the settlement boundaries in small rural communities. An adapted default typology for small communities may be an approach to improve the default data. This may be done in a case study analysis with specific focus on the community type.

Many studies and scientific approaches for building urban energy typology models are available. This data is very useful but needs specification for the application to the case study of Wolfhagen. Wolfhagen does not have a concise building typology model of the city structures and building uses. This situation is most certainly comparable to many small- and medium-sized communities. It is necessary to create a link between data which can be found in literature and studies to the real built environment of the city. To do this, building typologies are useful tools, since they can be linked to cadastral data of the planning authorities to obtain a geo-reference. With the help of geo-processing areas and in many cases also building types and uses can be derived from the data.

Nevertheless data validation for the building typology is difficult and time-consuming. Despite the information which is available at the planning authorities, often in print not digital, only site visits help to make the data basis more precise. A lot of interesting information, e.g. taken renovation measures, level of insulation, heating system is sensitive with respect to data security. Specific information can only be obtained and processed with permission of building owners.

For strategic energy transition planning the level of detail obtainable from the different sources must be regarded good enough although validation would be needed to prove the assumptions made.

7 Urban renewable energy production

"I would like nuclear fusion to become a practical power source. It would provide an inexhaustible supply of energy, without pollution or global warming."
Stephen Hawking

§ 7.1 Introduction and methodology

Renewable energy production is a fairly new field in the working spectrum of urban planning. Especially small rural communities possess large renewable energy potentials within their communal area with low residential densities and open agricultural spaces. For the vision to become a net-zero or plus-energy community as described in chapter two, these are the necessary preconditions. Rural communities have good options to achieve a certain degree of energy autonomy if they develop their renewable energy potentials. Since energy production is a fairly new task for urban planning, in the following some principle facts on the potentials and boundary conditions for the most common renewable energy plants are summarised as default data for the scenario application. The renewable energy modules are the most important elements in the scenario. Renewable energy is the only production potential in the energy system. All so-called renewables on earth we can use are based on one of three principal energy flows: geothermal energy, solar energy and gravitational energy. Figure 7.1 gives an overview of the conversion paths and forms of energy use. For small- and medium-sized communities only the indicated subset is elaborated for this thesis.

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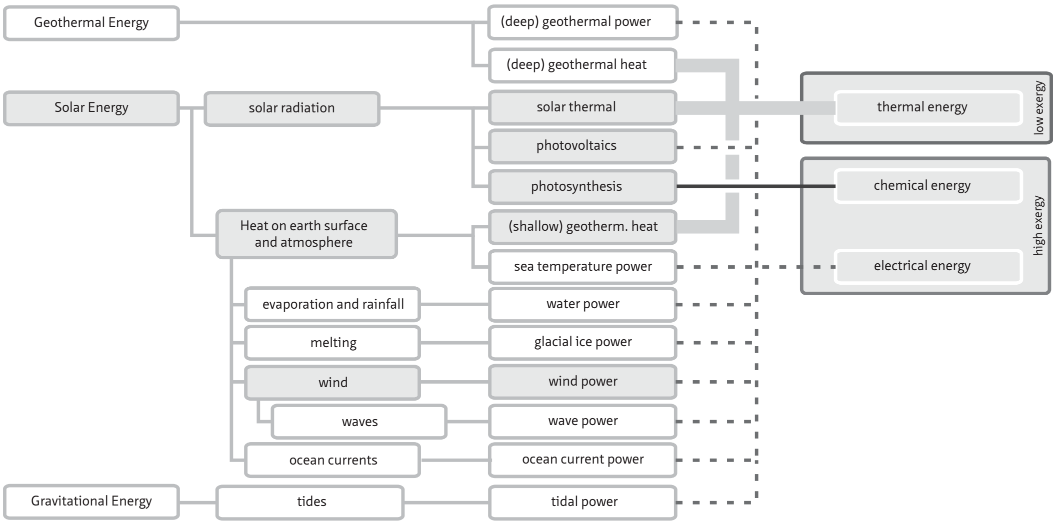

FIGURE 7.1 Options for the use of renewable energy sources

Because of the geographic location of the case study, the description of the renewable energy technologies is limited to on-shore solutions from wind energy, solar energy, biomass and shallow geothermal energy. The consequences of off-shore wind energy potentials for energy transition projects are discussed in the context of the Samsø project in chapter eleven. The options for deep geothermal energy use are only touched briefly because of the irrelevance for the case study.

§ 7.2 Solar energy

Harvesting energy from solar radiation is probably the most popular and universal approach for decentral renewable energy production. Other than wind energy, solar energy technologies can produce low-exergy heat at low or high temperature levels or high-exergy electricity (Figure 7.2). Both solar thermal collectors and photovoltaic panels can be located either on building roofs or on available open land of the community. The biomass potentials, as photo chemical conversion, is discussed in an extra section of this chapter.

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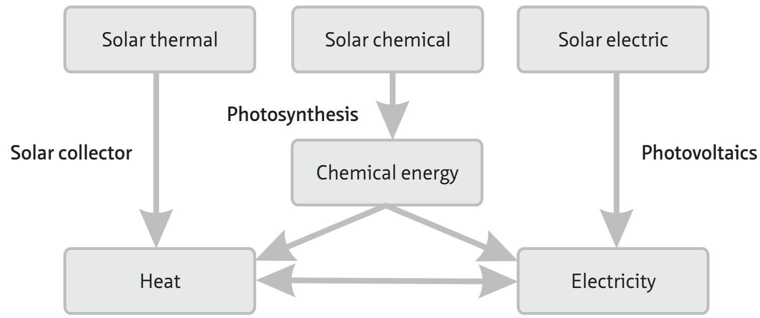

FIGURE 7.2 Conversion paths for solar radiation

For communal energy systems both thermal and electrical conversion paths are of central interest. Solar thermal applications can be used on a small-scale, for domestic hot water production and heating support of single-family buildings, or on larger scale as a contribution to decentral heat networks and storage systems. The relevance of solar electric energy production in combination with heat or cold applications via heat-pumps or direct heating and cooling in a smart-grid context will gain importance with the growing integration of electrical and thermal energy system components described later on in the 'Smart energy section' of this chapter.

§ 7.2.1 Section A: generic data on solar energy potentials

The energy radiation provided by the sun exceeds by far all present human energy demands. The utilisation of solar energy for heating and electricity purposes is the largest and most evenly distributed local energy potential. Solar radiation is almost mere exergy and can be converted into all the final energy forms as heat, electricity and chemical energy. The huge potentials and advantages of solar energy as primary energy source go alongside with some technical problems. Solar energy has a rather low power density. The solar constant that describes the solar flux density of electromagnetic radiation at the outside surface of the atmosphere is 1,361 kW/ m². The available energy from solar radiation on the earth's surface is reduced significantly by the transmission through the atmosphere, weather conditions and the geographical location, resulting in a worldwide daily (24 hours) average solar energy flux of approximately 165 kW/m². Solar energy is available for only half of the globe at a time. Its intensity is highly dependent on geographic location and weather. Despite its tremendous quantities solar energy is a rather unreliable energy source. For central Europe the yearly energy potential from solar radiation is approximately 1,000 kWh/ m², for comparison it is 2,350 kWh/m² in the Sahara region.

Nevertheless, the energy potentials of the sun are large, conversion technologies are market-proven and available and building structures provide large accessible surfaces for solar collectors and solar cells. Even limited to the technical potentials the overall solar radiation provided by the sun is large. Therefore the solar potentials deserve an exposed role within the energy model. Solar radiation cadastres and potential maps are popular and powerful tools to show individual options for renewable energy use and are already widespread in energy potential analysis on community or regional level (cf. Klärle *et al.* 2011). Based on the analysis of roof slopes, exposure and orientation a detailed potential analysis can be derived. This leads to a good assumption of the technical potentials for solar energy use on existing building surfaces.

As a generic approach the solar energy potentials can be connected to the settlement structures. In compliance with Hegger *et al.* (2012), the default values for solar energy potentials by settlement typology are given in Table 7.1[35, 36, 37].

35 Hegger et al. (2012) calculate the solar potentials based on the following assumptions. For solar thermal collectors the available roof area is multiplied with a factor of 0.7 to come to the technically feasible collector area. For this area the system efficiency is assumed with a factor of 0.35 and multiplied with the yearly global irradiation at an average German location (Würzburg climate) of 1,000 kWh/m². For photovoltaic plants the roof area is multiplied with a feasibility factor of 0.85 and an average system efficiency of 0.12.

36 For PV panels (ibid.) consider north oriented roof areas as well, while for solar thermal collectors only east, west and south oriented roof areas are used. The additional area for PV in north orientation is given in square brackets.

37 For the mid-rise housing slabs, an additional PV area of 365 m²/ha as non-building PV area (for instance on adjacent buildings, carports etc.) is assumed.

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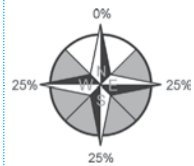
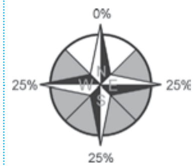
SETTLEMENT TYPE	ORIENTATION OF ROOFS	POTENTIAL ROOF AREA [m²/ha] AT SLOPE 30°		POTENTIAL FACADE AREA [m²/ha]		SOLAR POTENTIAL [MWh/ha]
Single and multifamily settlements of low density ST 1 / EST 1		N: [390]9	E: 390	not considered		Solar Thermal: 440
		S: 390	W: 390			Solar Electric: 156
Village centre and single-family settlements of high density ST 2 / EST 6		N: [1,059]	E: 1,059	not considered		Solar Thermal: 1,195
		S: 1,059	W: 1,059			Solar Electric: 425
Terraced Houses ST 3 / EST 2		N: 0	E: 1,627	not considered		Solar Thermal: 1,151
		S: 0	W: 1,627			Solar Electric: 329
Mid-rise housing slabs ST 4 / EST 3		N: 0	E: 1,344	N: [486]	E: 2,430	Solar Thermal: 2,146
		S: 0	W: 1,344	S: 486	W: 2,430	Solar Electric: 672
Medieval town centre ST 8 / EST 7		N: [2,481]	E: 2,481	not considered		Solar Thermal: 2,743
		S: 2,481	W: 2,481			Solar Electric: 975
Industry, Trade and Services	100 % flat roofs					

TABLE 7.1 Default values for solar area and energy potentials (from Hegger *et al.* 2012)

The assumptions lead to high energy potentials resulting from the high global irradiation values evenly distributed to the roof areas. Especially regarding the solar thermal potential, the feasibility depends on several preconditions of the demand side as well.

Based on the overall solar potentials, the technical feasibility constraints are discussed in chapter seven regarding the different scenarios. Using the default values of solar energy potentials in connection to settlement typologies gives a good first estimation and illustration of the high solar potentials available on existing building structures.

The identification of potential sites in Germany is connected to the regulations of the Renewable Energy Law (EEG). This law has undergone several amendments during the past years. On the one hand the guaranteed feed-in tariffs have been reduced in several steps for both roof-top and open-space plants, on the other hand reimbursement for photovoltaic-plants on open spaces were linked to conditions regarding the potential spaces. Since the 1st of January 2011 new plants have to be erected on conversion areas, for instance former industrial or military sites, to benefit from the guaranteed feed-in tariffs. Photovoltaic-plants on former agricultural or grasslands are no longer eligible. Open-space photovoltaic-plants have to be implemented in the land-development plans of the community. If there are available spaces within the community, the installation of open-space photovoltaic plants may be worthwhile. For open field installation typical net electricity potentials vary between 300 MWh/ha and year (Agentur für Erneuerbare Energien 2010) and 400 to 640 MWh/ha and year[38] (Arbeitsgemeinschaft Bayerischer Solar-Initiativen 2011; Klärle 2011). Open-field installations result in better production and economic efficiencies, nevertheless an analysis of potential spaces in the state Saarland in Germany has come to the result, that only a small fraction of potential spaces are really feasible for PV-modules (Klärle 2011) (Table 7.2)[39]. Therefore the potentials should not be overestimated in a first analysis.

POTENTIAL OPEN-SPACE FOR SOLAR ENERGY	TOTAL (A_{total})	REALISATION FACTOR (F_{real})	NET ELECTRICITY PRODUCTION PER YEAR [MWh/ha]
marginal-strips of high-ways and railway tracks	2.5 ha per km highway 1.5 ha per km railway	50 %	640
conversion areas	10 % of total	10 %	420
agricultural spaces and grassland	58 % of total	10 %	420

TABLE 7.2 Spatial potentials for open-space PV-installation (from Klärle 2011, own calculation)

38 comp. http://www.solaranlage.eu/photovoltaik/einsatzbereiche/freiflaechenanlagen, 21.Nov. 2013

39 The available area alongside highways and railroad tracks include a 110 m broad strip next to both shoulders (eligible according to EEG) less unsuitable spaces, spaces with less than 950 kWh/m² year global solar irradiation and spaces smaller than 1 hectare. Of the remaining spaces it is assumed that 50 % can be developed. For conversion areas 10 % of the total area complies with solar irradiation and size constraints. Of these 10 % are assumed to be potential development areas (1 % of total). Agricultural lands and grasslands comply at a higher rate to the irradiation and size constraints. The assumption for developments is set at 10 % as well. The last category of open-spaces is by far the largest, but is not eligible according to the EEG Klärle (2011).

As a general approach the potentials of open-space photovoltaic plants are calculated as follows:

$$P_{pv}open = (E_{global} \cdot A_{total} \cdot f_{eff} \cdot P_r)\, f_{real}$$

FIGURE 7.3 Equation 7 (comp. Klärle *et al.* 2011)

In the equation E_{global} is the global irradiation as average yearly sum. The spatial factor f_{eff} is the reduction factor for necessary distances between the module rows. In typical row-module installations 30 per cent of the area is covered with modules. P_r is the total performance ratio of the photovoltaic conversion of approximately 12 %.

For open-space installations row-modules or pillar-mounted tracker systems are available. Compared to row-modules tracking systems are more efficient because modules can be oriented ideally towards the sun (Table 7.3).

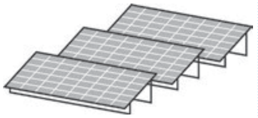
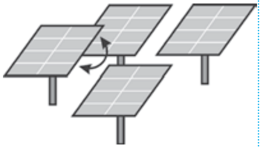
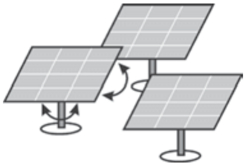
PV PLANT TYPE		EFFICIENCY-GAIN	NET ELECTRICITY PRODUCTION PER YEAR [MWh/ha]
Row-modules		0 %	420
Single-axis modules (tracker)		+30 %	546
Dual-axis modules (mover)		+40 %	588

TABLE 7.3 Efficiency gains of PV-trackers compared to row-modules

Based on the given literature data a rough estimation of solar energy potential within the community can be done even without a 3D roof topology analysis. Since the local conditions may deviate quite significantly from the default data a specification of the solar potentials based on the local conditions is reasonable to come to more meaningful results for the scenarios.

§ 7.2.2 Section B: specifications of generic solar energy potentials

For the calculation of the solar radiation on surfaces there are several simulation tools available. In this work the Solar Analyst Tool, a component of the ArcGIS Spatial Analyst tool box, is used. For the modelling of the solar energy potentials on a regional scale the topography has great influence on the distribution of the solar radiation. Slopes, exposition, ground elevation and the resulting shading influences the energy potentials from solar radiation. The modelling of solar potentials is done with the ArcGIS Solar Analyst tool, which calculates the sum of diffuse and direct solar radiation. According to the solar course the solar potential can be calculated from the digital height model (DHM). In a first step a theoretical solar potential is calculated which includes the total global radiation on tilted surfaces. From the total potential the technical potential can be derived by including the limiting factors for technical use of solar radiation as thermal or photovoltaic energy (Figure 7.4).

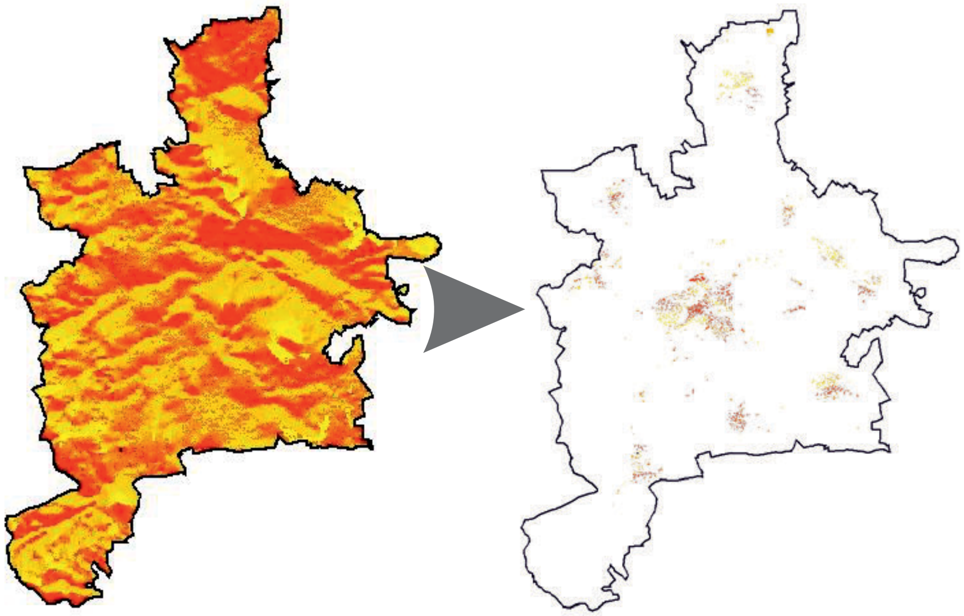


FIGURE 7.4 According to the technical constraints the total solar potential is reduced to the technical potential, in this case the available roof areas on the buildings of Wolfhagen (Hensel 2010)

The availability of GIS data allows a more detailed analysis of solar potentials on roof areas. Based on the ALK data of the city of Wolfhagen and the digital surface model, a more specific analysis of the solar energy potentials can be done. Based on two different methods the solar energy potentials of the city of Wolfhagen were analysed in two MSc thesis research projects. The central challenge of a specific solar energy potential map is the identification of potential roof areas with a good orientation. Negash (2008) based his analysis on the ALK data, which gave the base areas of the buildings but no roof directions and shapes. Negash assumed the roof slopes to be orthogonal to the longer side of the base area rectangle. This is true for the most typical gable roof forms. For hipped roofs and special roof types the approach produces positively biased results. The roof directions were calculated in ArcGIS with a modified code to get the azimuth angles (Figure 7.5). According to the deviation of the azimuth angle from the ideal south orientation the solar gains can be calculated with the reduction factors in Figure 7.6.

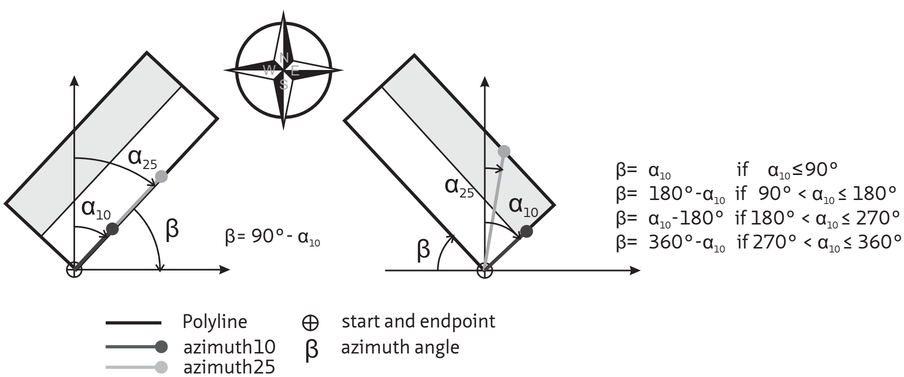


FIGURE 7.5 Scheme to calculate roof orientations from ALK polygons (Negash 2008)

	orientation						
	East			South			West
slope	90°	60°	30°	0°	30°	60°	90°
0°	83 %	83 %	83 %	83 %	83 %	83 %	83 %
10°	82 %	87 %	90 %	91 %	90 %	87 %	82 %
20°	81 %	89 %	94 %	96 %	94 %	89 %	81 %
30°	79 %	90 %	97 %	99 %	97 %	89 %	79 %
40°	76 %	89 %	97 %	100 %	97 %	88 %	76 %
50°	73 %	86 %	95 %	98 %	95 %	86 %	72 %
60°	68 %	82 %	91 %	94 %	91 %	82 %	68 %
70°	63 %	76 %	85 %	87 %	85 %	76 %	63 %
80°	57 %	69 %	77 %	79 %	77 %	69 %	57 %
90°	50 %	61%	67 %	69 %	67 %	61 %	50 %

FIGURE 7.6 Directionality of solar gains at Kassel location (Negash 2008)

The study was done only for the central city of Wolfhagen neglecting the villages and surrounding landscape. The roof slopes were estimated and averaged by an on-site analysis. For shading elements on roofs and other restricting factors for solar energy use literature values were used. It was assumed that 40 % of all principally suitable roof areas were not technically usable because of several constraints. For the technical potentials only roofs with more than 80 % solar radiation were considered. This excluded all north-oriented areas and facades. Nevertheless the study resulted in a total solar potential of 146.9 GWh per year on a total well usable roof area of 146,500 m². Since the 40 % reduction seems to limit the available roof space immoderately and the study only focussed on the sloped roofs of residential buildings and adjoining buildings, the results can be regarded a rather careful estimation of solar energy potentials in Wolfhagen.

Hensel (2010) carried out a specification and validation of this first study, based on a detailed digital roof model and digital surface model in GIS. Since in 2010 laser-scans were not available for the community, the digital surface model was approximated on the basis of freely available DOM raster data. The roof topology of the city of Wolfhagen could be modelled with greater precision including odd-shaped roofs as well (Figure 7.7).

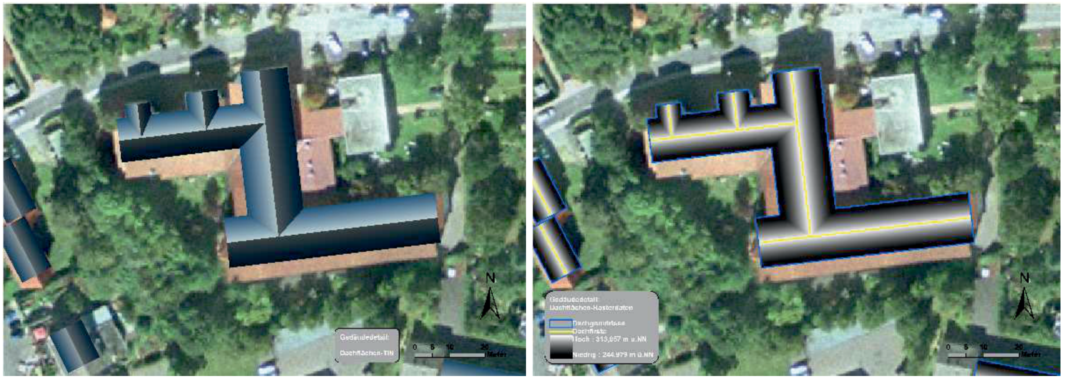


FIGURE 7.7 Roof modelling based on triangulation to get the roof model and conversion to raster data for the digital surface model (Hensel 2010)

With the digital surface model of the city, including the slopes and elevations of the hilly landscape and the elevations and roof shapes of the buildings, a detailed 3D analysis of the global irradiation was done (Figure 7.8).

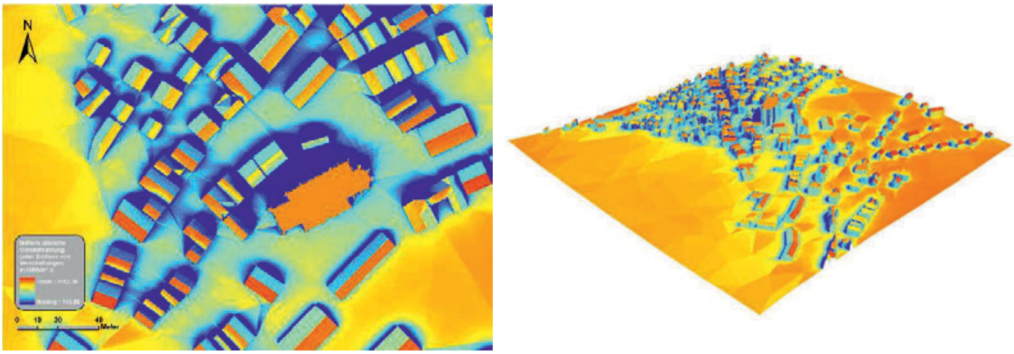


FIGURE 7.8 Yearly shading and average yearly solar irradiation in the 3D-city model (Hensel 2010)

The analysis gave a good validation of the remaining standard values in the first study. It could be shown that for the rather low-density structures of Wolfhagen the 40 per cent reduction for shading and other restricting factors was too high. With a detailed 3D modelling only five per cent of the potential roof areas had to be excluded because of shading (Hensel 2010). The study resulted in a total solar potential of 180 GWh global irradiation per year on a total roof area of 179,000 m².

For the modelling in chapter ten the detailed 3D model of the city of Wolfhagen was extended for the villages to give a specific overview on the solar potentials on roofs (Table 7.4). Since the available roof areas are large, façade areas are neglected. For a rural community this seems realistic.

TOWN DISTRICT	POTENTIAL ROOF AREA [m²]
Wolfhagen (town)	179,118
Philippinenburg und -thal	2,493
Altenhasungen	5,123
Bründersen	12,518
Gasterfeld	8,121
Ippinghausen	23,074
Istha	18,954
Leckringhausen	20,336
Niederelsungen	8,594
Nothfelden	8,449
Viesebeck	19,755
Wenigenhasungen	no validated data
(Elmarshausen)	no validated data
Total	306,536

TABLE 7.4 Areas for potential solar utilisation on building roofs with a yearly global irradiation > 820 kWh/m² and roof areas larger than 15 m²

The city of Wolfhagen has two large open-space photovoltaic fields. The older installation from 2009 is located close to the highway in the district of Niederelsungen with a total capacity of 1,980 kW_{peak}. The second open-space PV-installation is located along the B450 between Wolfhagen and Gasterfeld. On 18 hectare modules with a total capacity of 10 MW_{peak} started production in October 2012. With these two large open-space facilities the open-space potentials for the city of Wolfhagen are exploited. Since there are also large roof installations on the former tank garages in Gasterfeld, the potentials for large-scale eligible photovoltaic installations are limited. All existing PV-plants are included in the analysis in chapter ten. The scenarios in chapter nine base on the roof potentials rather than on further open-space developments.

From a planning perspective the question nevertheless arises of how to organise and structure the use of solar energy on roofs. In planning practice there are different and very controversial approaches. In 2008 the city of Marburg enacted a solar regulation of the city to make the use of solar energy mandatory for any new or large-scale refurbished buildings. This obligatory regulation caused severe protests and resulted in a court decision that criticised several aspects in the regulation but generally confirmed the legal foundation of the regulation in the building code of the state of Hassia. After the court decision the city of Marburg enacted the revised regulation in November 2011. In December 2011 the conservative government revised the Hassia building code, fully deleting the paragraph on which Marburg's solar regulation founded. Despite the protests of numerous supporters, this thitherto wrote finis under extended mandatory regulations on solar energy use from communal initiative. The estimated solar energy potentials for the entire community are very large. There are approximately 119,000 m² very well useable roof areas (>1,000 kWh/m²a) on residential buildings with a yearly solar radiation of 128,400 MWh. If the total number of usable roof areas are included, which are defined as all roof areas with more than 820 kWh/m² global radiation per year, the area potential more than double (Table 7.4).

The display and evaluation of the data in a building resolution allows the promotion of the thermal use of solar energy for residential purposes in a more direct and targeted way and to identify the ideal locations of PV plants. This can be integrated into the GIS tool as local energy service for residents and building owners.

§ 7.3 Wind Energy

The production of electricity by wind energy plants is a very attractive solution for communities that have suitable areas. Over the past decades wind energy plants on-shore have become more powerful and effective. This makes wind energy plants the 'high performers' of renewable electricity production. The wind energy potential is limited by the local wind speeds and available sites and the connection to the electrical grid. While the wind speeds are geographically determined, sites and grid integration can be handled by planning.

§ 7.3.1 Section A: generic data on wind energy potentials

Wind is a result of differences in the earthly radiance balance and zones with different air temperatures and pressures. Large scale pressure differences cause air movements as primary cause for wind. The local wind situation is very dependent on the local topography and climatic conditions and may differ significantly from the overall average. An important aspect of the wind energy potentials are the average yearly wind speeds. The average yearly wind speed is:

$$\overline{v_i} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} v \, dt \;\; (m/s)$$

FIGURE 7.9 Equation 8

With v being wind speed (m/s), t time (s) and t_2-t_1 time of one year. Such one year's averages are commonly taken for several years and calculated over the number of years:

$$\overline{v} = \frac{1}{n} \sum_{i=1}^{n} \overline{v_i} \;\; (m/s)$$

FIGURE 7.10 Equation 9

The minimum yearly average wind speed for an economic utilisation is given with different figures in the literature. While for a technical use the wind speeds at a height of 200 meters above surface are of interest, in the literature often other reference heights are given. The gradient of wind speed in the atmospheric boundary layer can be estimated according to the Hellmann potency law the wind as:

$$v_H = v_h \left[\frac{H}{h}\right]^a (m/s)$$

FIGURE 7.11 Equation 10

The exponent is dependent on the surface conditions with 0.1 for the open sea and 0.4 for a surface with large irregular barriers. For open flat land 0.14-0.2 and for forests 0.22 – 0.32 can be assumed. Rebhan (2002) states that an economically feasible wind potential starts at a yearly average of 4 m/s at a height of ten meters above ground. Other sources state 5.75-6 m/s at 140 meters height or 7.5 at 100 meters (RP Kassel 2011; Lensink & Faasen 2012). For a height of 200 meters above ground this means values of 7.28, 6.14 and 8.61 m/s average wind speeds. Wind maps show the distribution of typical wind speeds on a large-scale. From this a first overview on the potential locations can be derived (Figure 7.12). For implementation a detailed site analysis is necessary and the first step in the planning process. If there are data measurements available these can help to verify the data.

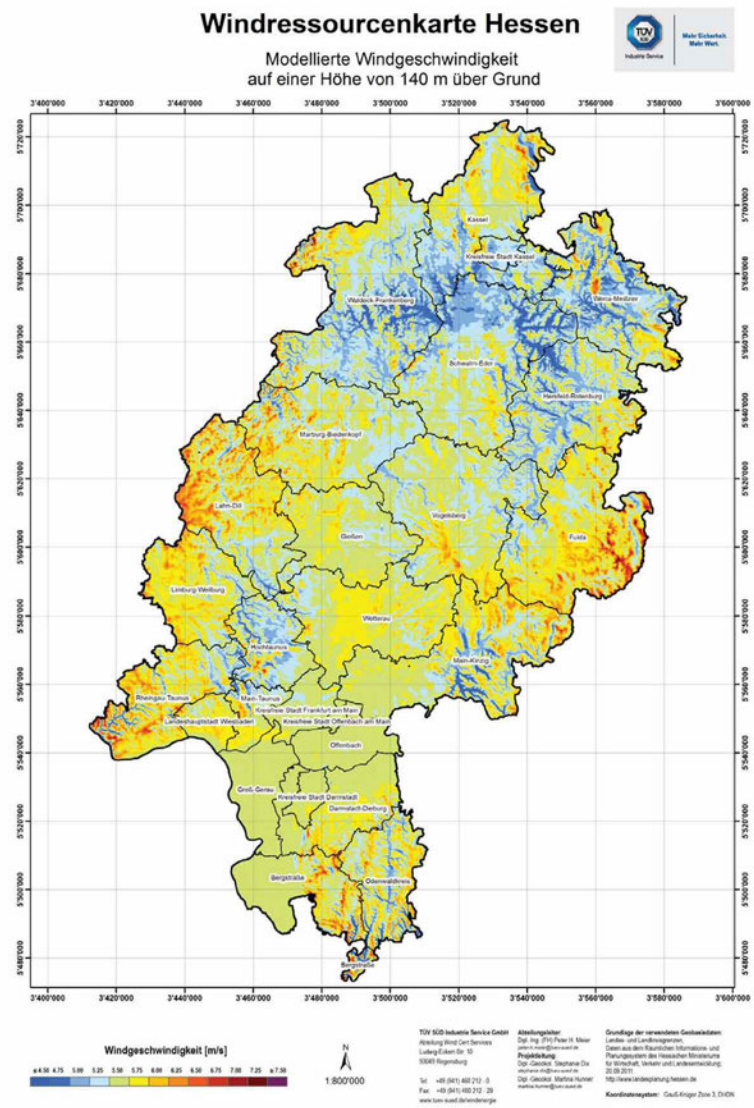


FIGURE 7.12 Wind potential maps of the State of Hessen at 140 m height (source: HMUELV).

The mechanical power P_{max} that can be harvested from an airflow depends in the third power on the wind speed, related to an area A perpendicular to the wind direction:

$$\frac{P_{max}}{A} = \frac{1}{2}\,\tilde{n}\,v^3$$

FIGURE 7.13 Equation 11

In this A is Area of the wind rotors with A = $R^2\pi$ (m^2). The radius represents basically the length of the rotor blades in metres.

The sizes of the wind energy plants for on-shore use have become more and more powerful over the past decades. Figure 7.14 shows the development of average power capacities, hub heights and rotor diameters for all installed onshore wind energy plants in Germany. The largest wind energy plant for onshore use is the ENERCON E 126 with 7.5 MW capacity and a rotor diameter of 126 meters. The more common installations today range between 2.5 and 5 Megawatt and hub heights between 80 and 130 meters (Table 7.5).

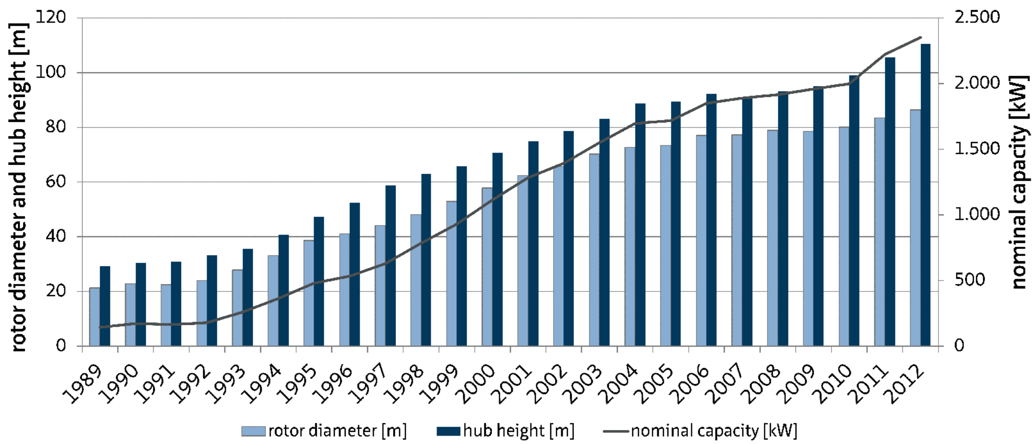


FIGURE 7.14 Development of average wind energy capacities and sizes. (source: http://windmonitor.iwes.fraunhofer.de)

	1980	1985	1990	1995	2000	2005	2010
capacity [kW]	30	80	250	600	1,500	3,000	7,500
rotor diameter [m]	15	20	30	46	70	90	126
hub height [m]	30	40	50	78	100	105	135
yearly energy production [MWh]	35	95	400	1,250	3,500	6,900	ca. 20,000

TABLE 7.5 Power development of wind energy plants (source: BWE 2012)

The energy production stated in Table 7.5 is not distributed evenly over the year. Wind is a fluctuating energy source. While the total production over the year is high at good locations there are also times of calms, when there is no energy from wind at all. For a good supply and demand matching it is important to achieve a good buffering and balancing of the fluctuating energy supply from wind energy. For a detailed analysis the profiles of the site have to be used. In a first step the monthly wind energy production is estimated from national statistics and scaled to the wind energy plants in the scenarios. This is to make planners and decision-makers more sensible for the need of good balancing, demand-side-management and storage systems to balance the energy system locally. In the winter months the energy production is higher than in the summer (Figure 7.15). During the summer months also the daily fluctuation is higher with a maximum between 13:00 and 17:00 (cf. IWES 2012, p.19).

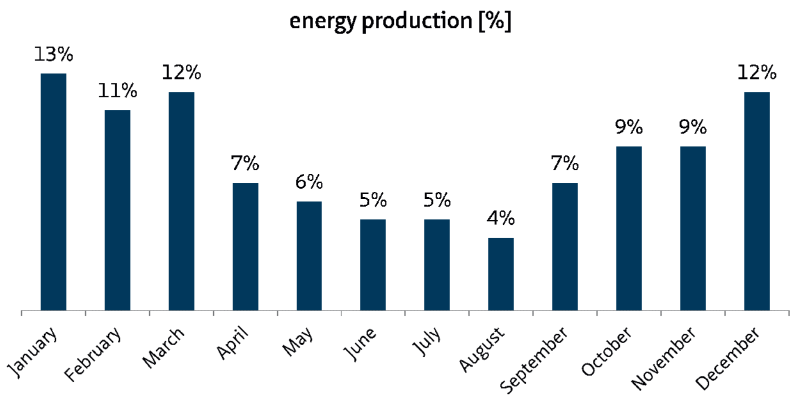


FIGURE 7.15 Energy production of an onshore wind energy plant over the months in a ten years average (source: http://windmonitor.iwes.fraunhofer.de)

One of the most significant advantages of wind energy use is the avoidance of pollutant emissions compared to conventional production in coal power plants. Directly on site the plants are emission free. Because of their high electricity output they amortise the energy used for production after three to six months (European Wind Energy Association 2010). Modern wind energy plants are made of steel to 82 % which can be recycled after the demolition. Concrete foundations can be used as secondary granulate for new concrete production or in infrastructure. Rotor blades are more problematic in reuse; these fibre-reinforced polymers have no recycling procedure yet, reason of which Dutch architects of Superuse Studio reused old blades for a playground in Rotterdam (Figure 7.16).

FIGURE 7.16 Playground elements made from used rotor blades. Design by Superuse Studio, picture by Denis Guzzo

The avoided CO_2-emissions by wind electricity production depend on the reference electricity mix. For the years 2006 / 2007 Klobasa *et al.* (2009) give a value of 781 gCO_2/kWh_{el}. With increasing shares of renewable energy in the overall electricity portfolio the amount of avoided CO_2 decreases. This has to reflect in the scenario with a declining factor, because otherwise the saving potentials are overestimated.

Generic data on wind energy potentials can be assumed similar to the potentials for open-space PV-installations. The available spaces for wind energy harvesting are limited and indicated in recommendations or regional development plans. Similar to open-space photovoltaic not all suitable spaces can be developed, which can be expressed with a factor freal. As a general approach the potentials of wind energy plants are calculated as follows:

$$P_{wind} = (A_{total} \div A_{turb} \cdot P_{turb} \cdot t)\, f_{real}$$

FIGURE 7.17 Equation 12 (comp. Klärle *et al.* 2011)

Aturb is the area necessary for one turbine, which can be assumed with 15 hectares for an average sized on-shore turbine. Pturb is the nominal capacity of the turbine and t are the full load hours which depend on the average wind speeds and the plant capacities. For instance, for an average wind speed of 5.5 m/s at 50 meters height a 2.5 MW plant approximately has 1,650 full load hours. If the wind speed is 6.5 m/s the full load hours are 2,450 (Klärle *et al.* 2011). For a first potential estimation an average of 2,000 full load hours are realistic (Bofinger *et al.* 2011).

Next to the large-scale wind energy plants that tend to become taller and more powerful to reduce the total amount of turbines, there are also options to harvest wind energy from small turbines up to 50 kW and a maximum height of 35 meters. These turbines are commonly located decentrally, directly next to buildings or farms to feed their electricity needs. The two main designs are horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT) (Figure 7.18). Most of these are installed predominantly on free-standing masts in open and exposed locations.[40]. In Germany all small wind energy turbines higher than ten metres need a building permission and the responsible State legislations and local authorities show little experience and different approaches in the approval practice.


FIGURE 7.18 Small-scale wind turbines of up to 1 kW nominal power as horizontal and vertical axis constructions (pictures left: wikimedia.org/commons, right: allsmallwindturbines.com)

40 http://www.renewableuk.com/en/renewable-energy/wind-energy/small-and-medium-scale-wind/technologies.cfm#sthash.RjAbxQkT.dpuf

To estimate the potentials of small-scale wind turbines the wind condition at the location is the crucial performance factor. Since the wind conditions vary significantly only measurements can deliver reliable data on the real wind conditions. For a first estimation of the electricity output moderate performance factors should be used. The electricity output can be estimated with the performance factors in Table 7.6 and the equation:

$$P_{wind} = P_{turb} \cdot f_{per} \cdot 8{,}760$$

FIGURE 7.19 Equation 13

In order not to overestimate the output, medium wind conditions are assumed for not fully exposed sites in the inland.

SMALL WIND TURBINE POWER (P_{turb}) [kW]	WIND CONDITIONS	PERFORMANCE FACTOR (F_{per})	ANNUAL ELECTRICITY OUTPUT (P_{wind}) [kWh]
1.5	low	0.11	1,500
	medium	0.17	2,250
	strong	0.23	3,000
	very strong	0.29	3,750
5	low	0.11	5,000
	medium	0.17	7,500
	strong	0.23	10,000
	very strong	0.29	12,500
10	low	0.11	10,000
	medium	0.17	15,000
	strong	0.23	20,000
	very strong	0.29	25,000

TABLE 7.6 Performance factors for small-scale wind turbines (from http://www.klein-windkraftanlagen.com, comp. Shaw et al. 2008)

§ 7.3.2 Section B: specifications of generic wind energy potentials

For the planning of a wind park the most important step is the identification of good sites with a high wind potential. In the German planning structure the definition of potential wind energy sites falls in the competence of the regional planning authorities. Therefore the regional 'wind energy' development plan is the most relevant document for the identification of potential sites (Regierungspräsidium Kassel 2013). The document gives detailed information on the criteria and exclusion criteria for the different potential sites. For the community of Wolfhagen there were four potential wind energy sites under consideration. Because of wind energy potentials, environmental concerns and technical constraints there is only one remaining potential development site for wind energy (Figure 7.20).

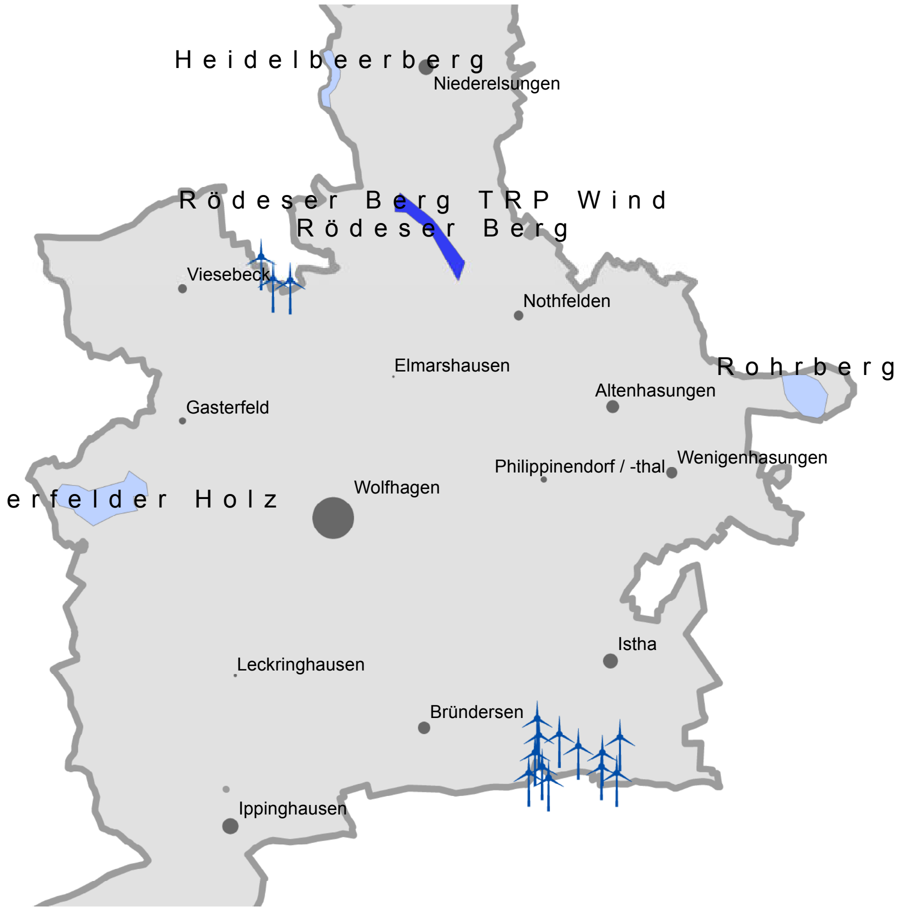


FIGURE 7.20 Of the four potential development sites only the 'Rödeser Berg TRP Wind' was recommended as wind energy priority site in the regional development plan (Regierungspräsidium Kassel 2013)

Commonly, wind energy plants are built on agricultural land, in open spaces. In the rural areas of the Central German Uplands many appropriate sites are covered with forests. With growing plant sizes and heights it is possible to exploit also wooded areas for wind energy use. The typical Middle European forest has a final grow height of 15 to 30 meters. Above the treetops there is a layer of 15 to 40 meters which is affected by the forest surface and characterised by high turbulences and low wind speeds. In heights of 30 to 60 meters these effects become negligible. Modern wind energy plants offer great opportunities for communities where the limited good wind energy locations are on top of wooded hills. On the other hand wind energy projects that affect forests are very sensible regarding natural protection requirements and public acceptance. It is therefore essential to start these with good participation and information processes.

For the location 'Rödeser Berg' this is the case. It is a forested hill-top site. On an area of nearly 42 hectares possible locations for wind energy plants can be identified. The development of wind energy plants is exclusively limited to this site.

In Germany wind energy plants with more than 50 meters total height require a building permission according to the Federal Emission Control Act. Smaller plants are approved by the urban planning authorities. For urban planning the wind energy sites are defined in the land development plan. Here potential sites can be mapped for further elaboration. Wind energy plants can only be built at a buffer distance of 1,000 meters away from residential buildings and buildings of mixed use to avoid noise disturbance (Figure 7.21). For industrial and commercial uses there are nor requirements defined. Most natural reserves are excluded from wind energy use. In the GIS protected areas and necessary distance to buildings can easily be represented and the potential sites are narrowed to realistic options.

For the site 'Rödeser Berg' an approval procedure for four wind energy plants was started in 2010 by the local energy association in cooperation with the local utilities. The four Enercon 101 plants have a total power of 12 Megawatts and will produce approximately 28 GWh of electricity per year. Since the wind energy plants start operation end of 2014 their production capacity will enter the scenario assumptions in Chapter nine. For large-scale wind energy plants the development on the 'Rödeser Berg' will be the only new development in the time frame of the scenarios. At the existing locations there is some repowering possible. Also there is some potential for small-scale wind energy. Especially for farms outside the town and village areas small-scale wind energy can be a good contribution to renewable energy production.

FIGURE 7.21 The potential wind energy site 'Rödeser Berg' is indicated grey. The buffering of neighbouring residential buildings shows that the site is mostly out of a 1,000 meter radius

§ 7.4 Biomass

For rural communities the use of biomass as energy potential is an option that may contribute significantly to the renewable energy production. While in the EU15 countries the share of biomass in the total primary energy consumption is approximately only 3 %, the more rural countries have the largest shares of biomass: Finland (18 %), Sweden (15 %) and Austria (12 %) (Rebhan 2002). In Germany biomass is mostly used as firewood and wood products for combustion, as wood pellets or wood chips. Additionally liquid biomass from manure and biogenic waste materials offers potentials in the energy system. Biomass is chemically bound solar energy and is therefore 'stored high exergy energy'. It is the only renewable energy source that is suitable for storage and demand-driven use. This means that biomass in a renewable energy system of the future has to fulfil the tasks of filling the supply gaps occurring in the fluctuating energy supply from solar and wind energy plants. Biomass is regarded a future source of material resources to supplement materials based on fossil fuels. In the general development of biomass potentials for energy supply biomass should therefore be regarded a limited and valuable resource, which should be integrated very efficiently and consciously in the communal energy system. In this regard the shift from fossil fuel furnaces in houses towards similar systems based on renewable biomass products (fire wood products) should be analysed critically with respect to exergy efficiency. Here the mere evaluation of CO_2-emission reduction omits central issues of future resource scarcities.

§ 7.4.1 Section A: generic data on biomass potentials

The bio-waste potential from households contains two components: food and kitchen waste and biodegradable garden wastes. The definitions of household waste components vary throughout Europe, so do the fractions of the different components in the total amount of household wastes. An overview on the situation in European countries can be found in Hogg *et al.* (2002) and Franckx *et al.* (2009). For Germany UBA & BMU (2012) gives a value of 108.9 kg bio-waste from households per person as a national average. Of these 52.2 kg are food and kitchen wastes and 56.6 kg are garden wastes. For a first approximation these figures can be used for the household bio-waste potential in the community. This is under the premise that a separate collecting system exists which is the case for less than 50 % of the inhabitants in Germany (UBA & BMU 2012).

For communities the biomass potentials can be differentiated into different sources and different uses. The biomass potentials on a settlement level were analysed by Hegger *et al.* (2012). The biomass considered for the energy potentials comes from organic household wastes and woody and herbaceous biomass from the settlement open spaces. The biomass is either harvested as green waste from open spaces and roads or in the case of small multifamily-buildings as well from an active plantation of biomass plants.

While the authors give a detailed description of the utilisation lines for each biomass type, the analysis of the energy potentials remains rather vague. Despite the fact that all biomass utilisations is assumed as either biogas or CHP plants, the energy potentials are solely referred to the heating potentials based on the efficiencies of a low-temperature boiler. It is unclear why the authors chose this approach, but presumably the biomass potentials on settlement level cannot be referred to in a simple building related approach as the solar energy potentials. When limited to the mere settlement spaces the biomass potentials are very small, which makes the configuration of a useful biogas of CHP plant impossible.

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The biomass potential for heating for the different settlement types is given in Table 7.7. To give a reference, the heating energy demand of the settlement type is given additionally, assuming a modern building structure, after 2002, or a fully refurbished building stock.

SETTLEMENT TYPE	BIOMASS VOLUME [t/ha]				CALORIFIC VALUE [MWh/ ha·a]	HEATING POTENTIAL [MWh/ ha·a]	HEATING DEMAND [MWh/ ha·a]	COVER-AGE
	waste	wood	crops	other				
Single and multi-family settlements of low density ST 1 / EST 1	2.1	0.6	-	12.3	16.1	13.7	162	8 %
Village centre and single-family settlements of high density ST 2 / EST 6	8.4	0.3	-	7.5	14	11.9	633	2 %
Terraced Houses ST 3 / EST 2	4.6	0.7	-	9.6	14.9	12.7	270	5 %
Mid-rise housing slabs ST 4 / EST 3	9.6	0.2	5.1	-	26	22	430	5 %
Medieval town centre ST 8 / EST 7	24.5	0.1	-	0.3	15	12.8	1,165	1 %

TABLE 7.7 Biomass and heating energy potential for settlement types (data from: Hegger *et al.* 2012)

The small coverage that can be achieved from the biomass potentials emphasises that biomass utilisation is crucially linked to space. Only for communities with large open spaces, forestry and agriculture there can be a significant biomass contribution in the energy balance. The denser the settlement structure, the smaller the potential contribution of biomass to the total heat supply. It is therefore necessary to take larger reference areas into account than the mere settlement areas. At the same time agricultural biomass production for energy competes with food production and other existing uses of agricultural and forest spaces. A rough estimate on the spatial demands is given in Table 7.8:

BIOMASS SOURCE	SPACE NEEDED TO PRODUCE 1 MWh ELECTRICITY PER YEAR [m²]
forest (forest residues)	approx. 2,000
grassland (feed grass)	approx. 330
cropland (energy plants)	from 125

TABLE 7.8 Space demands for the production of electricity from biomass (Klärle *et al.* 2011)

Significant biomass potentials can still be exploited from forestry, either as primary wood products, or as by-products and waste from wood-processing. The direct utilisation of wood products as firewood dominates the current biomass utilisation. Only 20 % of the total biomass used in Germany is used for electricity production. In any electricity process for instance biogas plants or CHP-plants on wood chips or straw, 75 % of the energy produced is heat. In exergy terms wood is a high-exergy source[41]. The fact that biomass is regarded CO_2 neutral neglects the fact that it is a limited, space- and time-dependent resource. Therefore the use of biomass in combined processes should always be connected to heat grids to make use of the process heat. This is of specific importance since the energy conversion efficiencies of photosynthesis are not very favourable and large spaces are needed. In Germany an average of 50 ton fresh mass (15 tons dry weight) of corn can be harvested per hectare. This results in approximately 17 MWh_{el} electricity and 40 MWh_{th} of heat if the biomass is used in a biogas CHP-plant. The comparison with the production potentials from solar or wind per hectare emphasis the focus on waste and by-product utilisation in the biomass sector to avoid land use conflicts.

§ 7.4.2 Section B: specifications of generic biomass potentials

As described in chapter five, the case study community is rural with large agricultural and forest areas (Figure 7.15). Basically biomass is available to contribute to the renewable energy supply. In order to analyse the existing biomass potentials in the

41 There is no common definition for the system boundaries of exergy calculation which has some effects on the rating of the renewable energy sources. There are experts who argue that a concise definition of boundary conditions would mean to take into account the primary extra-terrestrial energy input of the sun into account for the primary exergy factor of all secondary energy sources, for instance fossil fuels, biomass, electricity from solar or wind and solar thermal. Because of the low energy efficiencies of photosynthesis and biomass production this leads to extremely low efficiencies for biomass and even wind energy. Since the question of conversion efficiencies becomes relevant after the question of spatial use and potential energy production densities, the question of concise boundary conditions for primary exergy factors has only little practical relevance in urban planning. In this thesis local biomass sources are regarded as chemical exergy sources whose central advantage lies in storability. This follows the approach of experts who consider exergy analysis mostly a tool for optimisation of technical energy conversion processes (comp. www.annex64.org).

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community a MSc thesis research was executed in 2013 under supervision of the author (Seel 2013). On the basis of the digital maps the different agricultural and forest spaces were calculated. Forest data could as well be extracted from the data provided by the local forestry office and state forestry office.

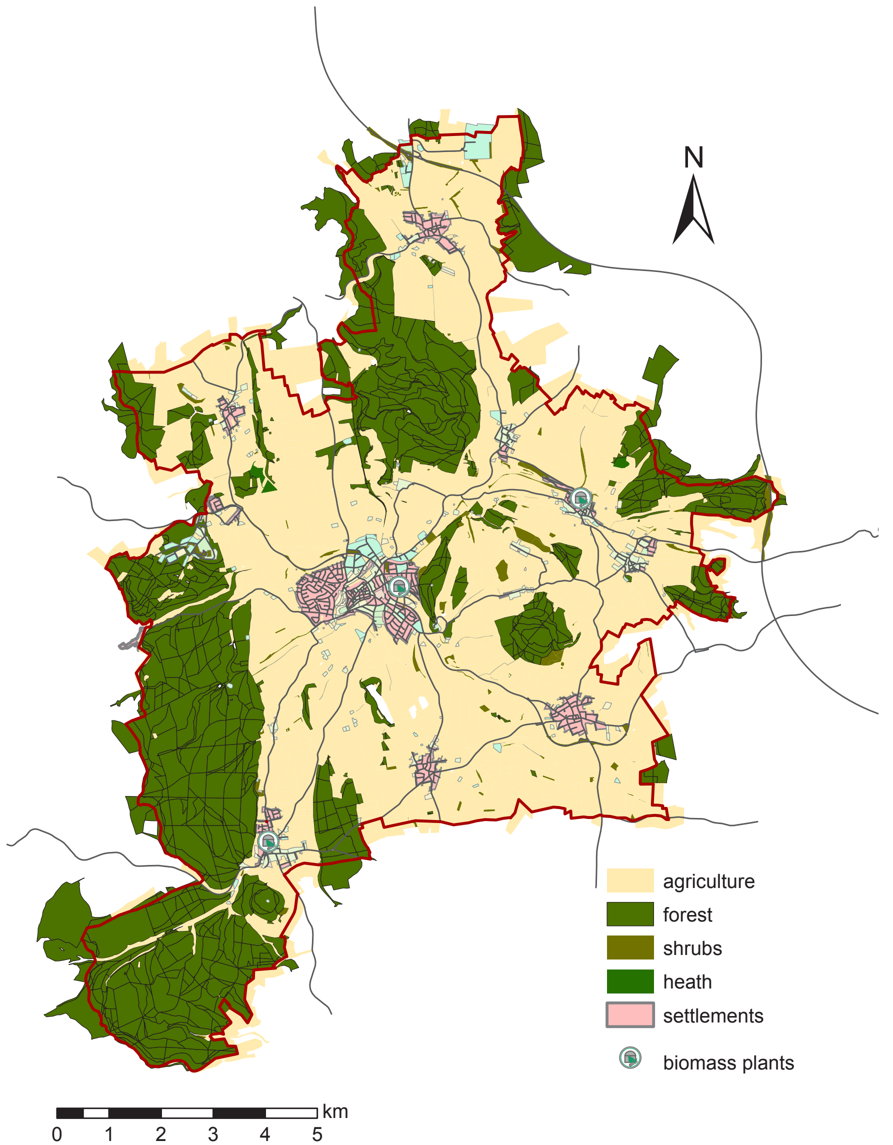

FIGURE 7.22 Rural structure and biomass potentials of the community of Wolfhagen

The inventory results of the forestry and agricultural spaces in Wolfhagen can be found in Table 7.9.

BIOMASS POTENTIAL SPACES	TOTAL [ha]	SUB-CATEGORIES	SPACE [ha]
forest	4,748	deciduous forest	1,044
		coniferous forest	1,084
		mixed forest	2,620
agriculture	5,850	cropland	3,961
		grassland	963
		fallow land	926
others	18.31	orchard meadows	10.89
		tree nurseries	7.42

TABLE 7.9 Agricultural spaces in the community of Wolfhagen (Hessisches Statistisches Landesamt 2012)

To obtain a better data basis on biomass potentials, it is necessary to analyse the different potential sources according to ownership structures and existing utilisation chains as shown in Figure 7.23.

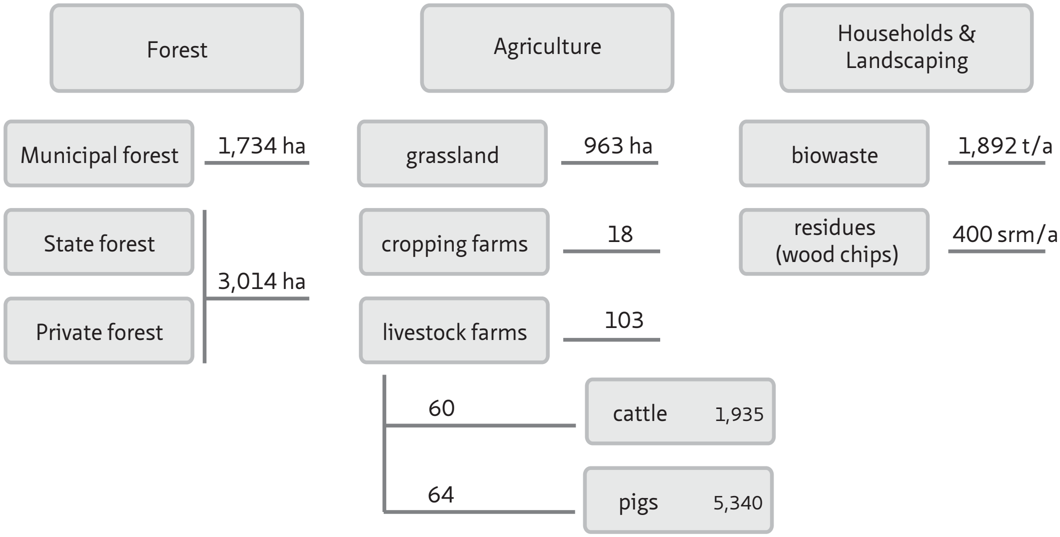

FIGURE 7.23 Analysis scheme to obtain specific biomass potential data

The potentials in the section households and landscaping were fairly easy to obtain, since there is an existing collection system for household bio-waste and the landscaping residues are cut and collected by the communal landscaping services. The inhabitants produce approximately 135 kg of bio-waste per inhabitant and year. This means that the bio-waste potential in Wolfhagen is above German average. This can be explained by the rural environment with an above average size of gardens. The bio-waste and the landscaping residues are already used as bio-energy sources outside the system boundary. In the categories forestry and agriculture a more detailed analysis is necessary because of the more complex production and utilisation situation.

Data on wood yields are available from the municipality forestry office. Since at the time being no specific data for the state forest and private forests is available, the data from the municipal forest is extrapolated to all forest areas, assuming that both wood stock and yields are comparable. In forestry management wood harvesting is planned for ten-year periods. Every decade an inventory is done and cultivation strategies and business plans are determined. Table 7.10 gives an overview on the harvest data of the municipal forest and the extrapolation to the State and private forest areas.

MUNICIPAL FORESTS						STATE AND PRIVATE FORESTS		
Area [ha]	Tree-type	Stock [m^3]	Harvest [m^3_{brut}/a]	Harvest [m^3_{net}/a]	Residues [m^3/a]	Area [ha]	Harvest [m^3_{net}/a]	Residues [m^3/a]
1,733.8	beech	154,263	5,528	all	all	3,014.12	all	all
	oak	58,352	868.4					
	spruce	219,570	6,847.2					
	pine	117,705	2,318.7					
	total	549,890	15,562.3	12,449	3,890		21,644	6,762

TABLE 7.10 Timber stocks and harvest based on municipal forest data (data source: Wolfhagen Forstamt)

The total timber harvest of 34,093 m³ per year could certainly be used energetically. According to the municipal forestry office currently only 15 % of the total timber harvest is used as firewood. For Wolfhagen this would mean an additional yearly firewood potential of 5,114 m³. Of the harvest residues 10 % may be used energetically. The rest contains small branches that remain in the forest to maintain the soil fertility. The total amount of forest residues for energetic usage is approximately 1,065 m³/a without utilisation conflicts.

The crop land in Wolfhagen is used for the production of different crops. The distribution of crop land and harvest values is given in Table 7.11. For production of grains the regional farmers' association gives a harvest value of seven tons of fresh mass per hectare for the community of Wolfhagen. Specific data on harvest results was not obtainable because of data privacy.

CROP	AREA [ha]	HARVEST FRESH MASS [t_{ave}/(ha·a)]	STRAW [t_{ave}/(ha·a)]	TOTAL HARVEST [t/a)]	TOTAL RESIDUES (STRAW) [t/a]
corn	162	55	-	8,910	-
wheat	1,532	7 (corn only)	5.6	10,724	8,579
barley	862	7 (corn only)	4.9	6,034	4,224
triticale	85	7 (corn only)	5.6	595	476
rye	55	7 (corn only)	6.3	385	347
rapeseed	688	3.8 (corn only)	7.22	2,614	4,967
total				29,262	18,593

TABLE 7.11 Cropland distribution and harvest in Wolfhagen (sources Hessisches Statistisches Landesamt 2012; Kaltschmitt 2009)

Similar to the approach for the wood biomass potentials, only the residues or straw potentials may be regarded non-conflict potentials to be used energetically. Usually not the entire amount of straw is taken from the fields to maintain the fertility of the soil. The total amount of straw retrieved is not known specifically for Wolfhagen, Zeller *et al.* (2012) give a rate 62.5 % as an average of straw production. Of that value approximately fifty percent are used as bedding of feed for livestock. Rapeseed straw usually remains on the fields because of its inhomogeneous structure. For the scenarios based on biomass these limitations are taken into account.

Residues from livestock production can as well be used as bio-energy sources. For Wolfhagen Seel (2013) calculated a total potential of 29,354 m^3/a of liquid manure from cattle and 10,814 m^3/a liquid manure from pigs. At the time being this is used a fertilizer.

The last biomass potential source taken into account for Wolfhagen is grass from feedgrass pastures. From typical pastures an average fresh mass production of seven tons per hectare can be assumed. From the 963 hectares this makes a total grass potential of 6,741 t/a fresh mass. Mass losses for biogas utilisation can be assumed at 10 % (Kaltschmitt 2009), for burning up to 25 % mass is lost, due to dehydration.

Other biomass potentials, for instance from short rotation forestry, are not existent in Wolfhagen at the moment. The question to what extent biomass may contribute to the renewable energy balance in Wolfhagen and how biomass potentials may be extended is covered in the scenarios in Chapter nine. It became clear that in contrast to other renewable energy potentials, biomass is already used to a large rate and therefore any extended energetic use may cause resource conflicts.

In 2009 the consulting company Pöyry Environment GmbH finished a feasibility study for a biogas plant on the area of the former military facilities in Gasterfeld (Einzmann 2009). In its first section the study included the collection of basic data on available biomass potentials and options of technical use. The studied area for the biomass potential analysis is significantly larger than the system boundary in the project and included Wolfhagen with 48 communities and four cities. In the potential analysis bio waste, green wastes, wastes from landscape care, wastes from sawmills, matured and waste timber and the agricultural waste materials straw, manures and energy crops included.

In total the author of the study identified an energy potential of 3,100 MWh per year for the waste materials (Table 7.12). For burnable biomass there is a potential of about 21,600 MWh per year and the total amount of resources available for fermentation (cattle manure and silage maize) offers a potential of 70,400 MWh per year. The full potential is not exploitable because of utilisation competitions.

BIOMASS	AVAILABILTY (TONS PER YEAR)	ENERGY POTENTIAL (MWh PER YEAR)
Waste products for biogas		
bio waste from households in Breuna, Wolfhagen, Naumburg	3,835	3,000
lop	250	100
renewable resources for biogas		
liquid manure	25,000	2,700
silage maize	92,500	67,700
ligneous biomass for burning		
lop	250	500
landscaping residues	200	400
saw mill residue	4,350	8,700
forest wood	6,000	12,000

TABLE 7.12 Biomass potentials in the larger area of Wolfhagen (from Einzmann 2009)

The free timber potential is currently fairly much exhausted, meaning that for the extension of the biomass burning on the facility sites regional and partly inter-regional fuels have to be bought.

§ 7.5 Geothermal energy

The hot core of the earth contains a giant energy reservoir of approximately 10^{13} EJ. The average energy flow towards the earth's surface is approximately 80 mW/m² (Rebhan 2002). The utilisation of geothermal energy can be differentiated into deep and shallow geothermal systems. Despite the fact that the energy flow from geothermal is roughly 2,000 times smaller than the solar radiation the potential especially for the shallow geothermal energy as a renewable sustainable heat source is large. It is easily accessibility in most areas and can be used on small and large scale. Compared to solar and wind energy geothermal energy is available without severe fluctuations over the entire year which makes it a good renewable heat source. The available temperatures underground vary according to the geological and hydrological conditions. At sites with shallow volcanic regions and tectonic cliffs the available energy flow can be much higher. Therefore larger scale geothermal energy exploitation demands a detailed knowledge on underground conditions. The average temperature gradient from the surface down is 3 Kelvin per 100 metres depths. In some areas in Germany there are more favourable conditions, mostly in the North and in the South. Along the Upper Rhine Rift, at the foot of the Swabian Alb and in some areas of the Northern German basin the gradient shows five or even ten Kelvin temperature rise per 100 meters depth (Sass *et al.* 2011). The distribution of newly installed geothermal power plants in Germany is therefore distributed unevenly. The German Geothermal Association (BVG) publishes a yearly ranking of new geothermal installations via their website[42]. Included are all ground-coupled heat-pumps that received funding via the Federal Renewable Energy Incentive Programm. While 595 new geothermal heat-pumps with a total capacity of 9.7 MW have been installed in the State of Bavaria in 2015, only one 10 kW heat-pump was installed in Bremen. The State of Hessen ranked 12th with 54 systems and a total capacity of 804 kW.

§ 7.5.1 Section A: generic data on geothermal potentials

Shallow geothermal systems

Systems that use the shallow geothermal energy potential commonly use underground heat exchangers, boreholes with closed loop systems or underground water reservoirs

42 http://www.erdwaermeliga.de/erdwaermeliga-bundesliga.html

to extract geothermal energy. The depth usually doesn't exceed 140 with 400 meters at the most. The exploited water temperatures can be used for heating only after a temperature lift. Typically heat pumps are the most favourable systems to do that. The underground heat exchangers need to keep a certain distance between each other to avoid over-exploitation of the soil and to allow the temperatures to fully recover over the seasons. Therefore the options for the integration of larger numbers of underground boreholes are better in less dense urban structures. Whereas finding enough space for boreholes for individual buildings can be problematic in denser existing urban settlements. Here a heat grid solution with a central borehole field might be an option to realise a larger scale geothermal energy supply (cf. 8.3.1).

In Germany there are approximately 333.000 shallow geothermal systems installed. The overall capacity is approximately 3,900 MW. There are approximately 17,000 newly installed systems per year in Germany[43]. These include all systems not only the systems which received funding.

General figures on geothermal potentials for different settlement types can be found in Table 7.13. This evaluation is based on a spatial evaluation of available open spaces in the settlement typologies and the necessary distances between boreholes and towards neighboring plots. According to Swiss surveys the distnace shouldn't be less than five meters (Eugster *et al.* 1992). The figures can be used to get a first rough estimate on geothermal potentials in the different settlement types.

SETTLEMENT TYPE	NUMBER OF BOREHOLES [n/ha]	ENERGY POTENTIAL [MWh/ha·a]
Single and multifamily settle-ments of low density ST 1 / EST 1	94	1,558
Village centre and single-family settlements of high density ST 2 / EST 6	19	319t
Terraced Houses ST 3 / EST 2	42	691
Mid-rise housing slabs ST 4 / EST 3	106	2,004
Medieval town centre ST 8 / EST 7	9	158

TABLE 7.13 Spatial potential for boreholes and heating energy potential for settlement types (data from: Hegger *et al.* 2012)

43 Source: Bundesverband Geothermie (www.geothermie.de)

The underground can be a useful long-term heat and cold storage. To estimate the potential of geothermal heat and cold storage the specific underground conditions are crucial. In stable hydrogeological and geothermal situations surplus solar thermal energy can be stored using the geothermal boreholes while cool return flows can be used for comfort cooling in summer. An overview on ground-coupled systems and their parameters can be found in Zimmerman (2003). To make efficient use of geothermal energy in combination with heat pumps the required temperatures for heating should be as close to room temperature as possible. A supply temperature of 35°C is recommended. Floor heating or wall heating systems contribute to the overall efficiency of heat pumps based on geothermal energy. This makes geothermal heating systems very attractive for new buildings because in the case of highly efficient new constructions all benefits of the geothermal energy source can be fully used.

Deep geothermal systems

Deep geothermal wells offer the opportunity to use the geothermal heat without additional heat pumps to raise the temperatures. According to this definition deep geothermal energy exploitation strives for depths of more than 400 meters and temperatures above 20°C. Commonly deep geothermal energy starts at approximately 1,000 meters depth and 60°C water temperature. There are different technologies to exploit the deep high temperature geothermal resources (Figure 7.24). Regarding the energy use systems can be differentiated into systems that use underground water reservoirs or aquivers and systems that use the heat stored in underground rock. The temperatures range from thermal (>20°C) to warm (60 to 100°C) and hot (>100°C). Reservoirs above 100°C can be used for electricity production.

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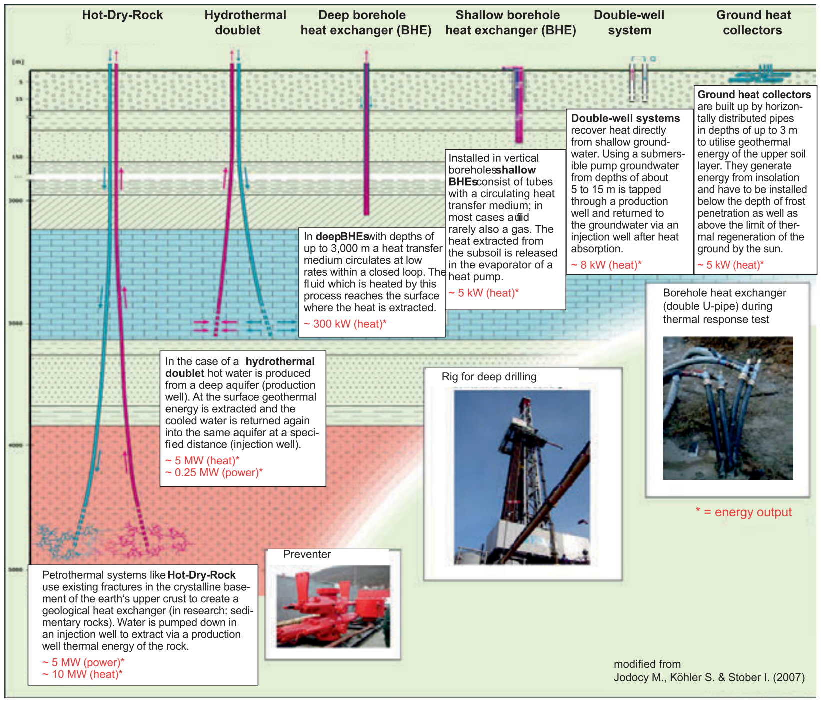

FIGURE 7.24 Examples of different deeo geothermal energy systems (Source: Stober, I. *et al.* 2014)

The warm reservoirs can be used to supply distict heating grids without additional heat pumps at required district heating supply temperature. Therefore the largest number of operating deep geothermal plants produce heat for district heating networks. In Germany 33 plants have been in operation at the beginning of 2016. Three projects are under construction and 30 projects are still in a planning stage. 21 of the operating plants are located in southern Bavaria where there are the most favourable geothermal conditions. Consequently the city of Munich regards deep geothermal heat one of the most important renewable sources to achieve a hundret percent renewable goal in the heating supply. The largest plants have a thermal capacity of 38 MW_{th} each and are located close to Munich in Oberhaching, Unterhaching and Taufkirchen.

All of these are hydrogeothermal plants. This means that they use deep aquifers and extract hot water which is run over a heat exchanger and reinjected into a second well. For this the hydraulic conductivity is important next to the available temperatures to ensure a sufficient production rate. The surveys for hydrogeothermal energy plants include geological as well as hydrochemical analyses and drilling tests.

A special type of deep geothermal energy use is the exploitation of underground water reservoirs in caverns or former mine shafts. These huge underground water reservoirs are geothermal energy sources and offer possibilities for seasonal heat and cold storage. One large scale project based on geothermal minewater at a large scale was realised with the Minewater Project in Heerlen, The Netherlands (Figure 7.25). A total of five wells were drilled into the underground mineshafts to exploit warm water (28 °C) at a depth of 700 meters in two shafts and cool water (16 °C) at a depth of 250 meters from another two shafts. The third shaft serves as reinjection well to obtain a closed system. A seven kilometer three-pipe distict heating network supplies low-temperature primary energy for heating and cooling to more than 50,000 m² of residential, commercial and office spaces. The temperature lift, if necessary, is done in central energy stations or directly in the buildings. The system started operation in 2008 and is currently undergoing an optimisation process called Minewater 2.0. This shows the huge long-term potentials to integrate new renewable or waste heat sources and connect them to the underground storage volumes (Verhoeven *et al.* 2014).

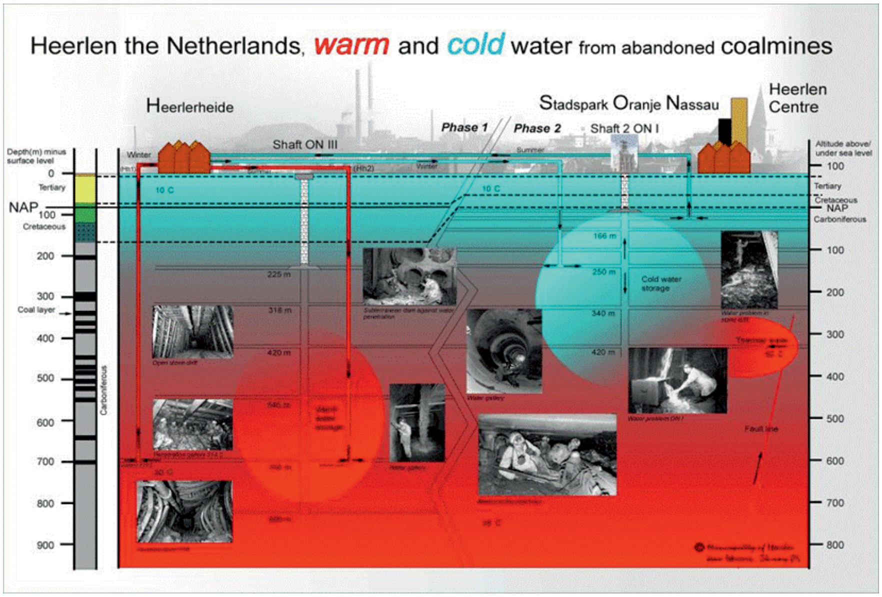

FIGURE 7.25 Scheme of the geothermal energy conceopt in the Minewater Project Heerlen (Source: Cauberg Huygen R.I.B.V.)

The minewater project is a good example of a full-scale low-exergy concept as described in chapter 2.4.4. The project shows the potentials of a strict low-exergy approach with geothemal primary sources, low temperature heating and high temperature cooling networks and adjusted building systems.

§ 7.5.2 Section B: specifications of generic geothermal potentials

There is no specifically good geothermal situation for the case study community. The entire area is mostly prohibited or retentional geothermal area. This is mostly caused by the strict water protection regulations the State of Hessen has set up. This means that geothermal energy use, drilling and heat extraction at shallow levels is in principle possible except in the red areas where geothermal heat exploitation is prohibited by a stae regulation from 25th August 2011[44] (Fig. 7.26). For the individual drilling permit in the yellow and orange areas a permit may be given on a case-by-case basis.

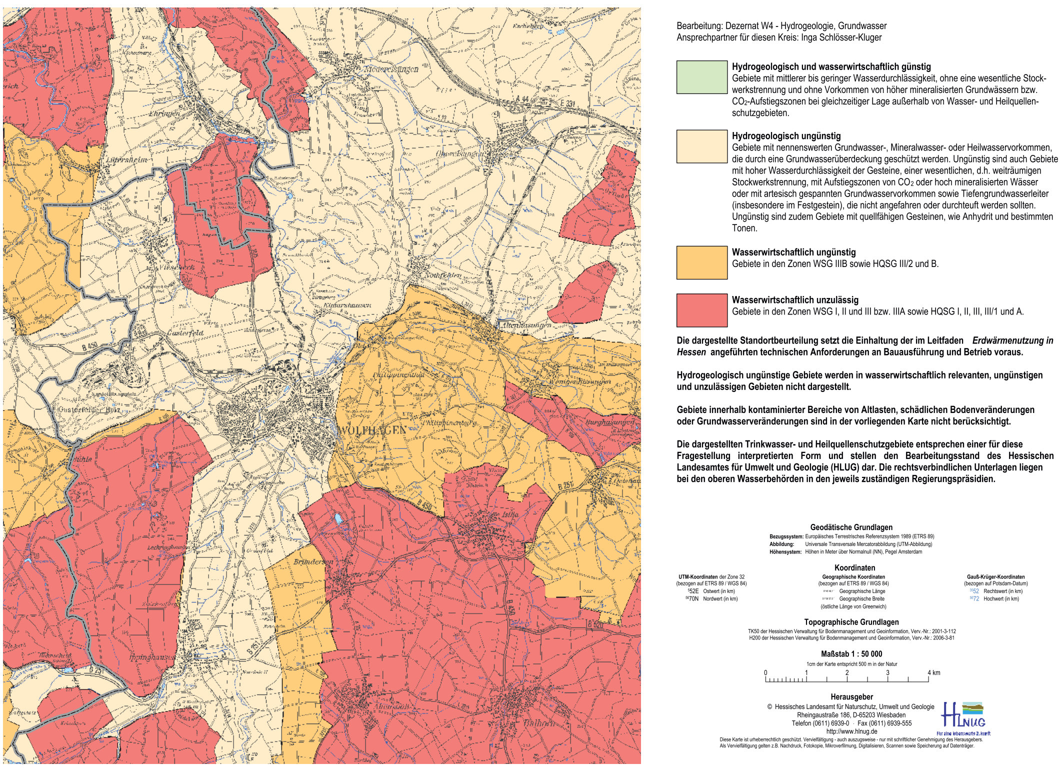

FIGURE 7.26 Geothermal exploitation map based on water provison and hydrogeological restrictions (source: LHNUG)

44 Hessisches Ministerium für Umwelt, Klimaschutz, Landwirtschaft und Verbraucherschutz, Erlass vom 25.August 2011 (St.Anz. S. 1228)

For the model there is some potential assumed for shallow geothermal energy use. This mainly reflects in the increase of heat-pump systems in the two scenarios with significant increase in renewable energies in the heating sector. Because of the limitations for geothermal energy exploitation in Wolfhagen the primary energy source for heat pumps has been left open though.

If in the future there will be developed more decentral small-scale heating-grids there might be options to integrate semi-central borehole-fields to contribute to the base-load heat supply for the networks. These systems could as well integrate a solar thermal heat recovery in the summer using cost-efficient uncovered absorbers. This concept is currently being developed for a new construction site in Kassel-Wehlheiden[45] and could be further developed for other sites as well. An important precondition for a low-temperature supply system is a reduced energy demand for heating and low supply temperatures in the heating systems. Therefore these concepts have to be combined with demand reduction and refurbishment measures if they are to applied in the existing building stock.

§ 7.6 Conclusions

Compared to the available data on building level the renewable energy potentials can be calculated to a good extent from physical parameters. For both wind energy and solar energy potentials the data which can be derived from the higher-scale sources can be used to build a sufficient potential map. More problematic is the situation for biomass and forest and agricultural residues. Especially the question of utilisation conflicts and already existing utilisation lines for the different biomass products cannot be broken down to the community situation in a very specific way. On the other hand specific data on available and potential biomass resources are difficult to obtain because of data protection and small-scale scattered ownership of spaces.

Regarding the three different potential renewable energy sources it can be stated that the potentials to harvest solar energy are large; even if only roof-top installations and well-suitable orientations are taken into account. This is a good precondition to implement a larger share of solar-thermal installations and pv-plants. The challenge for exploiting these scattered decentral and rather small solar sites lies in a good grid integration and necessary grid extensions. The possibilities to install large-scale open-

45 http://stadt-kassel.de/aktuelles/meldungen/20240/

field pv-plants has been limited to specific areas, for instance military or industrial conversion areas or areas along interstate highways or railroad lines, by the current Renewable Energies Act (EEG). For the case study of Wolfhagen the question whether there are more feasible sites for large scale pv-plants will be more a political than a geographical issue, since there are already several large scale plants in operation.

Wind energy creates the largest energy harvest per square-meter, if referenced to the necessary installation sites. Since large-scale wind energy plants have to reach up high into the sky, the most promising locations are up on hill-tops. This makes the plants visible over long distances and creates a larger 'landscape-impact' than the solar plants. The utilisation of existing wind energy potentials is closely connected to public acceptance. For the case study of Wolfhagen the four realised wind energy plants on the Rödeser Berg probably set the limit of public acceptance to the exploitation of wind energy potentials in the community in the near future. It is questionable whether the high national goals for on-shore wind energy can be actually exploited under the influence of diminishing public acceptance.

The biomass potentials for energetic utilisation are not as high in quantity in rural communities as one would assume. Most biomass is already bound into utilisation chains other than energy. Especially community and household bio-wastes are demanded resources that are transported over the system boundary. The existing agricultural structure cannot easily be converted into an energy supply system at once. Agriculture is quite conservative and changes from food-farming towards energy farming will take a long time. Nevertheless there is significant potential especially for future residual load biogas-CHP plants and with them new income opportunities for farmers. All the publically owned forests can be regarded well-cultivated with the central aim of delivering solid profits from a sustainable management of the existing and growing stock. This means that energy use of forest biomass is only the second or even third best use after a construction or raw material use. The biomass potential will therefore practically be limited mostly to waste material flows. There is some geothermal energy potential mostly for shallow geothermal systems. Nevertheless small districts of Wolfhagen lie in specifically protected areas where geothermal energy use will demand specific permission.

The analysis of the most central renewable energy potentials in rural communities shows a broad variety of options for an increased exploitation of renewable sources. These sources can be of high or low exergetic quality and there are fluctuating as well as storable energy sources available. It has to be stated though that the potentials for fluctuating energy flows are by far greater than for the storable resources. This increases the demand for flexible and cross-sectoral solutions in the energy system.

8 Implementation of a sustainable energy system in communities

"Technology is nothing. What's important is that you have a faith in people, that they're basically good and smart, and if you give them tools, they'll do wonderful things with them."
Steve Jobs (1955 - 2011)

§ 8.1 Introduction and methodology

In this section all system components are summarised that allow a better balance between the demand and the supply side. The focus is mainly on options to improve the renewable heat supply, since this sector has developed rather slowly in the past. This means that the strategies and modules of this sector mainly serve both the renewable electricity system and the renewable heat supply with the aim to create better utilisation efficiency for both. For the electricity sector this mainly is the field of Demand-Side-Integration technologies with a strong focus on heat pumps as heating systems and options of power-to-heat technologies, for instance with thermal storage, which allow an efficient shift of renewable surplus electricity to the heat sector. The storage of electricity, for instance in batteries, is not covered in this dissertation because this section covers the link between the electricity and the heat sector. For the heating sector local energy grids can operate in a way that the overall balance and exergy efficiency of the energy supply can be optimised. These small local grids can operate on low temperatures and integrate both waste heat potentials and power-to-heat systems. The available general reference data is still scarce for this sector and case studies are mostly in a research or test phase.

§ 8.2 Demand-Side-Integration

The sector of Demand-Side-Integration can be divided in two sectors. Apel *et al.* (2012) summarise Demand-Side-Management (DSM) and Demand-Side-Response (DSR) under the term Demand-Side-Integration. In the IEA task 8 (Roberts 2006) Demand-

Side-Response is named Demand-Side-Bidding. The definitions of the two columns are similar and are given in Figure 8.1. Demand-Side-Management means the active activation or deactivation of loads within the electricity grid to avoid load peaks and to stabilise the electricity grid by the grid operator. This already is an old technique used for instance via night storage heating systems to stabilise the load curves. Demand Side Response means the response of the consumer to price signals or incentives from tariff models and an increased flexibility to use off-peak electricity.

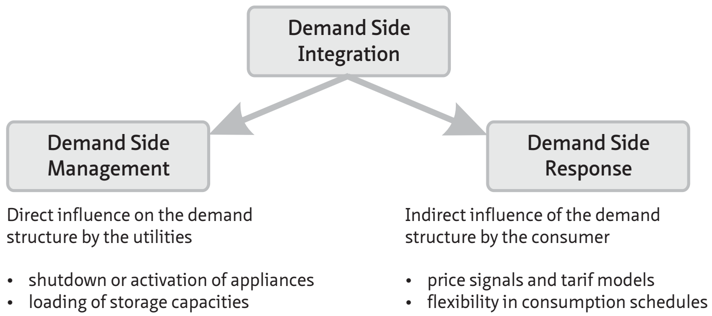

FIGURE 8.1 Definition of terms for Demand-Side-Integration (after Apel *et al*. 2012)

In this thesis no detailed overview on the mechanisms of Demand-Side-Integration is given. For a technical overview there are detailed studies available, for instance (Apel *et al*. 2012), (Roon *et al*. 2010) or (Klobasa 2007). For the purpose of this thesis only the systems for residential applications are touched with regard to their load shifting potentials.

§ 8.2.1 Section A: generic data on demand side integration technologies

The modelling of the effects of increased flexibility of household appliances, heating and domestic hot water production on the local electricity load curves is very complex and the research is developing very dynamically. A detailed demand-side-integration model on the basis of settlement typology was developed for instance by Metz (2014). A model on appliances and correlating load curves was developed by Stamminger *et al*. (2009) and Stötzer (2012). All these approaches include a detailed analysis of the load duration curves in the supply grid and the effects of load-shifting and load-smoothing by demand-side-integration. For the aims of this thesis these approaches are too detailed and complex to be integrated in the decision support toll at this moment. In order to come to a simplified approach and useful assumptions for the scenarios the model region study of Apel *et al.* (2012) contains useful results. On the basis of an artificial model region the authors elaborate effective potentials for the reduction of load peaks for target year scenarios (Table 8.1).

	2010			2020			2030		
Summer	P_{max} [%]	P_{min} [%]	P_{diff} [%]	P_{max} [%]	P_{min} [%]	P_{diff} [%]	P_{max} [%]	P_{min} [%]	P_{diff} [%]
Work day	-1.6	11.6	-6.8	-8.6	26.4	-22.0	-10.7	54.5	-27.0
Saturday	-4.7	21.9	-21.4	-9.3	33.9	-36.0	-16.6	61.2	-44.9
Sunday	-5.0	22.3	-21.7	-11.0	32.5	-37.5	-19.6	60.1	-50.3
Winter	P_{max} [%]	P_{min} [%]	P_{diff} [%]	P_{max} [%]	P_{min} [%]	P_{diff} [%]	P_{max} [%]	P_{min} [%]	P_{diff} [%]
Work day	-4.9	9.1	-9.0	-9.5	25.0	-20.1	-10.9	49.4	-24.2
Saturday	-8.0	25.7	-21.3	-12.2	39.9	-30.9	-17.4	52.5	-35.0
Sunday	-9.0	31.3	-24.9	-14.0	39.6	-35.8	-18.2	60.9	-41.2

TABLE 8.1 Results of optimisation of standard load profiles (from Apel *et al.* 2012)

The scenarios assume a significant increase in thermal installation for Demand-Side-Response applications such as heat pumps, cooling devices and suitable domestic hot water systems. The model also includes the demands for trade and service applications and for the year 2030 a significant share of electric mobility. The model therefore is not fully comparable to the scenarios in this thesis. Some central findings are nevertheless helpful for a simplified approach to Demand-Side-Integration potentials.

An average of 16 % of the actual electricity demand can be regarded suitable for load-shifting under the present conditions. An increase of the load-shifting potentials is mainly connected to the development of heat applications such as heat pumps and domestic hot water production. This stresses the importance of future power-to-heat concepts. For the hot water production Stadler (2006) assumed that approximately 25 % of the electrically produced hot water demand is suitable for Demand-Side-Integration. This is because of the large share of flow-type heaters.

§ 8.2.2 Section B: specification for the case study conditions

There is no specific data on the suitable Demand-Side-Integration potentials in the case study of Wolfhagen. The local utility company is preparing a field-test to acquire data for both Demand-Side-Management and Demand-Side-Response aspects. For the moment there are no existing applications for Demand-Side-Integration available in the case study despite the few heat pumps. No smart-meters are installed in the households and there are no night storage heaters in Wolfhagen, which could serve as easy accessible potentials.

The potentials of load-shifting with heat pumps are currently being modelled in a PhD project at Fraunhofer IBP. The central question is the share of surplus electricity suitable for heating via heat pumps with a certain degree of thermal free flow of the thermal building masses. To analyse the potential contributions of Surplus renewable electricity the supply is compared to the demand on an hourly basis (Figure 8.2).

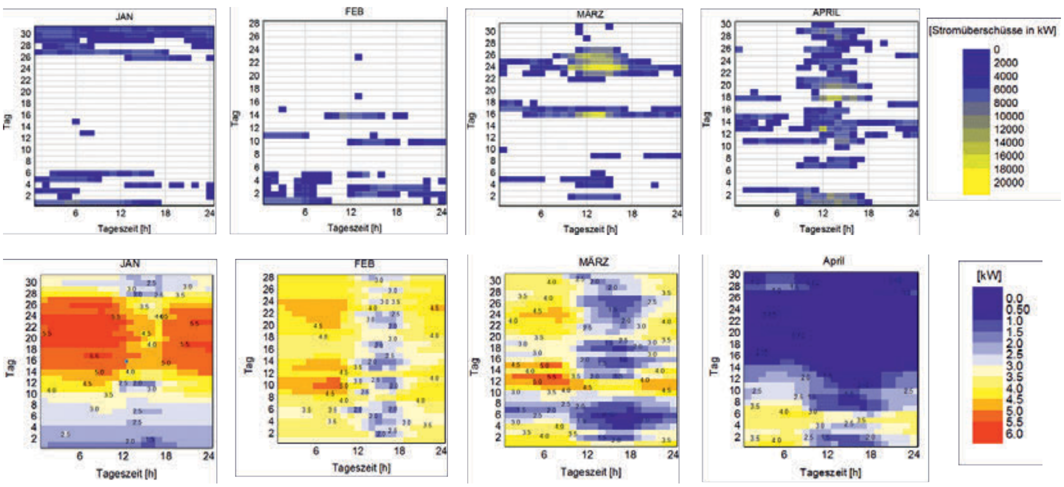

FIGURE 8.2 Top: Hourly distribution of electricity surplus in the Wolfhagen grid. Bottom: Heating energy demand of a single-family house (source: Young Jae Yu, IBP)

From the overview it becomes clear that a direct use of surplus electricity is not a feasible solution because of the significant timely mismatch. Power-to-heat solutions demand the integration of storage capacity either as thermal building mass or thermal water storage.

§ 8.3 Urban energy networks – smart energy management

One central element to optimise an energy system under exergy principles are local heat grids. Heat grids can be regarded as the missing links between heat consumers and renewable energies (Nast 2007). Urban heating networks allow the distribution of heat from different renewable sources, for instance waste heat, solar heat and CHP plants to the consumers. Heat grids allow the bundling of numerous heat consumers to one larger and smoother profile allowing the installation of more effective large-scale renewable energy conversion technologies. For instance, utilisation of agricultural waste products such as straw is only possible in central heating stations. The same holds true for forest residues such as wood chips or bark. Only via heat grids waste heat from industrial processes or biogas plants can be transported to the households. At the same time the heat grids offer options for 'power-to-heat' strategies by supplying storage capacities and a load-smoothing effect for the demand side. For small- and medium-sized communities in Germany the supply with district heating is rather exceptional. On national scale in 2010 approximately 7.8 % of the final energy used for heating was supplied via district heating (AGEB 2013); approximately 14 % of the households are supplied with district heating. District heating systems can be found mostly in the dense cities and agglomeration areas. The development of district heating grids has not been very dynamic over the past decades in Germany. An increase of 0.2 % can be regarded as stagnation in district heating development. In the share of district heating supply Germany ranges below European average (Figure 8.3).

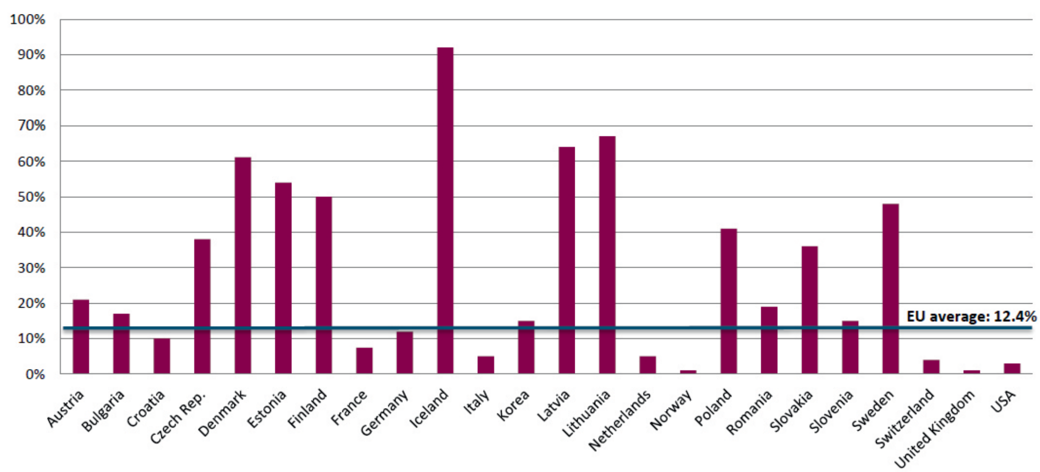

FIGURE 8.3 Share of citizens supplied by district heating (Euroheat & Power 2013)

The options for the realisation of district heating solutions are determined to a great extent by the built environment and the settlement structures. The feasibility of district heating grids depends to a great extent on the density of the energy demand, meaning the amount of energy sold per meter of supply line. On the absolute limits of feasibility there are quite different opinions in the countries. While in Germany the average amount of energy sold per meter of grid length is above 4 MWh, the value is only about 1 MWh in Denmark, where even low-density rural areas are accessed with district heating.

§ 8.3.1 Section A: generic data on urban energy networks

Planning principles on concepts of local district heating (DH) grids can be found in numerous publications e.g. Dötsch *et al.* (1998), Lutsch *et al.* (2004b), Fischedick *et al.* (2006), Esch *et al.* (2011) and Blesl *et al.* (2012). All authors start the analysis of local district heating systems on the settlement typology and the heating requirements and densities of the building structure for heating and domestic hot water. Lutsch *et al.* (2004b) regard very low density and sprawled settlement structures as not feasible for the development of district heating solutions. Typical figures for the settlement typology according to Lutsch *et al.* (2004b)[46] and Lutsch *et al.* (2004a)[47] are given in Table 8.2.

ISOMETRIC SETTLEMENT TYPE	BUILDINGS PER ha	RESIDENTIAL UNITS PER ha	DISTRICT GRID/ SERVICE PIPE [m/BLDG.]	DISTRICT HEATING LOSSES [%]	HEAT DENSITY [MWh/(ha·a)]
Single and multifamily settlements of low density ST 2 / EST 1	14 / 11.43	21 / 10	15 / 8	18	256.18
Village centre and single-family settlements of high density ST 3 / EST 6	68 / 10.89	86 / 10	14 / 6	14	256.01
Terraced Houses ST 4 / EST 2	35 / 18.13	35 / 70	6/8	15	273.16
Mid-rise housing slabs ST 5 / EST 3	17 / 6.89	104 / 70	13/10	6	430.21
Medieval town centre ST 9 / EST 7	114 / 32.52	260 / 100	6/6	7	1,033.22
Industry, Trade and Services ST 10 / EST 10		individual analysis necessary	133/25	6	344.40

TABLE 8.2 Typical figures for district heating-system potentials for the settlement typologies

46 The figures give the median values from Hegger *et al.* (2012) (first figure) compared to the assumptions of Lutsch *et al.* (2004b) (second figure)

47 Heat density data source: Lutsch *et al.* (2004a) p.99

The estimation of heat demand per spatial unit is very dependent on the assumed number of buildings and residential units. The feasibility of district heating systems is then dependent on the assumed heating demand per hectare. The configurations of the model settlement typologies in literature vary quite a bit. The given values should therefore only be used as first very rough estimation and need verification for the local conditions.

The distribution grids are the main factors for the investment costs of new local heat grids. There are development projects going on mainly in Scandinavia to reduce the grid costs by more efficient pipeline and insulation materials. The heat losses from the distribution grid can be reduced by a reduction of the supply temperature. Denmark, being pioneer in both the development of the overall share of district heating supply and the development of rural low-density areas with district heating has embedded the reduction of supply temperatures in their renewable strategy plans to create a 100 % renewable heat supply by 2050 (Dalla Rosa 2012). The temperature levels of the supply have to be reduced continuously to allow an efficient integration of renewable energies (Figure 8.4).

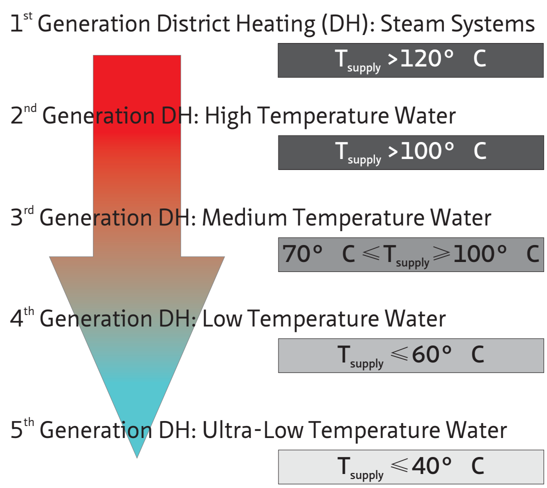

FIGURE 8.4 Reduction of supply temperatures in the DH for the integration of renewable energies (after Dalla Rosa 2012, IEA TS1)

Under the precondition of reduced supply temperatures, a geothermal and solar thermal supply of the heat grid becomes possible. Also the integration of low-temperature waste heat is possible. The reduction of the supply temperatures demand measures on the building side as well. Energy efficiency measures reduce the necessary heating power and allow, at best in combination with floor heating systems, very low supply temperatures. As a transition technology based on renewable energies available

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biomass resources can supply higher temperature of the 3rd or 4th generation from central CHP plants. To reduce the return temperatures in the grid for higher system efficiency, refurbished buildings with low heating requirements may be connected via the return line as well. The domestic hot water demands can be supplied via the DH with temperatures above 60° C. For the low and ultra-low DH systems decentral hot water systems which supply hot water on a demand-driven basis can contribute to the overall system efficiency. As elaborated in 8.2.1 decentral hot water storage may serve as a power-to-heat module as well.

The European project CELSIUS[48] which is funded under the European Union's Seventh Framework Programme for research, technological development and demonstration is working on the integration of innovative heating and cooling networks on district and city scale. The central goal is to reach a better efficiency in waste heat utilisation and a more focussed connection of different utilisation combinations. The five partner cities London, Rotterdam, Gothenburg, Cologne and Genoa provide numerous implementation examples for system integration, sustainable heat and cold generation, storage solutions and infrastructure. Despite the fact that the implementation of renewable and low temperature heat and cold supply is still not common practice the demonstrators show many examples of feasible solutions. On the scale of a regional development plan for a long-term and successive development of low-temperature supply grids Broersma et al. (2013) did a study for the Dutch communities Pijnacker-Nootdorp and Lansingerland. With the help of Energy Potential Mapping (comp. 3.2.3) the natural and anthropogenic energy sources were analysed and options for utilisation strategies were developed. These can lead to a concise Energy Master Plans as described by Van den Dobbelsteen, A. A. J. F. et al. (2014) that give far more detailed information than foreseen in the legal procedures of an urban energy plan as proposed by Blesl *et al.* (2012) (comp. 1.1.3).

§ 8.3.2 Section B: specifications on urban energy networks

The case study shows settlement characteristics feasible for the development of local district heating solutions. To evaluate the potentials of different settlement typologies of the case study MSc thesis research was done by Kilian Stroh in 2013 at the University of Kassel under the supervision of the author. The focus was laid upon the central town of Wolfhagen to get a first impression of the parameters and boundary conditions for local district heating. For the analysis the building structure was split in

48 http://celsiuscity.eu

five segments with different characteristics (Figure 8.5). For the analysis the central parameters of the identified settlement zones were determined from the existing GIS-data framework. The heat density describes the spatial energy demand for heating and domestic hot water of the zone in MWh/(ha*a). The linear heat density refers the value to the length of the supply grid in MWh/(m*a) and represents the energy sales via the grid. The latter is the most significant value for the feasibility of the grid and it depends on the refurbishment activity (more refurbishments, less energy sold) and the connection rate to the grid (the more, the better). For the study a feasibility limit of 250-300 MWh/(ha*a) was defined for a first evaluation of the different alternatives. Next to the total amount of consumers connected to the grid, the speed and direction of the connections are important aspects as well. In the scope of the Master's thesis the refurbishment rate was assumed with 1 % per year. A variation of connection rates was neglected.

FIGURE 8.5 Settlement zones for local district heating potentials (from Stroh 2013, own illustration)

A first comparison of the spatial heat densities of the defined zones results in the figures given in Table 8.3.

	NUMBER OF BUILDINGS	AREA [ha]	DEMAND HEATING AND DOMESTIC HOT WATER [MWh/a]	HEAT DENSITY [MWh/(ha·a)]
1 – Medieval town centre	479	41	26,405	644
2 – Sprawled single-family houses	149	18	2,690	154
3 – Single and multi-family buildings of low density	508	59	12,839	217
4 – Mid-rise housing slabs & single-family settlements of high density	310	48	15,369	320
5 – Single-family settlements of high density	270	29	10,426	359

TABLE 8.3 Evaluation of settlement structure for local district heating (source: Stroh 2013)

The evaluation shows that the areas with sprawled single-family buildings are not very promising for the development of local district heating grids. The highest demand side densities can be found in the old town centre and here a development of a medium-temperature local district heating grid could be a promising solution to reach a 100 % renewable supply since the large numbers of existing historic buildings show severe limitations for building retrofitting. The detailed streetwise analysis of (Stroh 2013) on the historic town centre will be used as reference for the application of the scenarios in chapter ten. The parameters are transferrable to similar village centre structures in the city districts.

§ 8.4 Influences of habits and user-behaviour

The technical issues elaborated in this chapter aside, energy consumption patterns are influenced to a large extent by individual behaviour. This section will give a brief overview of this topic to add the approach of social sciences to this thesis. In any planning discipline there cannot be any implementation without understanding of some correlations aside from technical issues. The implementation of these aspects in the scenario application is of a qualitative basis. The following sections give an overview and help the interpretation of results.

§ 8.4.1 Life-styles, milieus and demographic aspects

Even though most people would consider themselves environmentally conscious and energy aware, the real developments do often not reflect this. The results from the research in social sciences on lifestyles and social milieus are used to examine and explain these discrepancies. Unfortunately there are no simple answers or one-to-one causalities between the social groups and the energy consumption. Borgstedt *et al.* (2010) analyse and describe the relationship between environmental attitudes and social and cultural factors grounded in social milieus. This analysis is done to use the concept of different social groups, attitudes and behaviour to design environmental policy strategies, e.g. by Cervinka *et al.* (2003). In some social studies a differentiation is made between the concept of a social milieu and the concept of lifestyles. Rössel & Otte (2012) define lifestyle as a pattern of organising every-day life that shows a certain formal similarity and a high biographic stability. Lifestyles are anchored in personal orientations and can be identified by other people. This makes the lifestyle a concept to describe the individual characteristics of a person. In the concept of social milieus, e.g. the Sinus-Millieu® concept used in commercial market-research, people are grouped by their principal orientation and values but additionally aspects of their social environment, such as income, housing and education are used for attributing the groups. In social milieus the boundaries are not drawn very distinctively, there are overlaps and intersections.

Thio & Oertel (2012) argue that the concept of the Sinus-Milieus is not unproblematic. Because people move between different social environments the defined placement in one milieu group, based on individual values and behaviour patterns is not constant. This again groups people according to their beliefs and attitudes. This moves the approach close to the lifestyle types, which are based on individual values, and does not give information on the influence of the social environment on the behaviour. The second disadvantage of the Sinus-Milieu concept can be found in its commercial application: not the entire method is published and accessible.

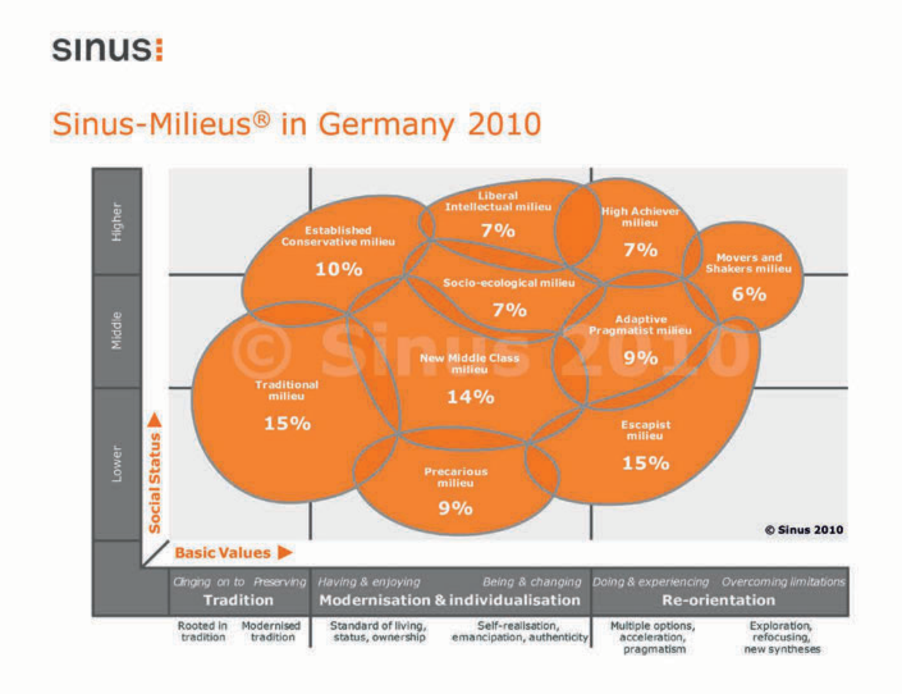

FIGURE 8.6 The Sinus-Milieus in Germany (source: Sinus Institut Heidelberg). Each milieu is described by their values, social classes and social environments (source: katharinara.files.wordpress.com)

While the vertical axis of Figure 8.6 follows the classical concept of social classes, the horizontal axis also implements a vision of the change in societal values theories which is more difficult to interpret. From the 'traditional' towards the 're-orientation' milieus, a change from materialism towards post-materialism is anticipated. Reusswig *et al.* (2003) argue that the differentiations on the horizontal axis, which are mostly characterised by individual lifestyles, have made the definition of homogenous groups more complex and behaviour less predictable.

Despite the methodological differentiations and scientific discussions on causal argumentation, the central finding in the context of energy systems is that there is not one Western European lifestyle that needs to change for a successful energy transition process. Although there are only few quantitative research results on the relationship between energy consumption and lifestyle, it is already clear that a differentiated view is helpful. Perrels & Weber (2000) have performed a study on the specific energy consumption by sector and different household categories in Germany, France and the Netherlands and the CO_2-emissions resulting. From questionnaires and the analysis of statistical data this way a diverse picture of some principle relations could be obtained.

In the study some dominant correlations were found. For instance, the household size was the most important factor to determine the energy consumption of electric equipment and domestic hot water. In contrast, the study showed only small correlations between the socio-demographic characteristics and the energy demand for space heating. Here user-behaviour seems to prevail. Perrels & Weber (2000) differentiate between direct and indirect energy consumption of households. Direct energy consumption is measurable at the household by electricity and fuel bills. Indirect energy consumption is measured outside the system boundary of household but induced by the family's preferences and decisions, for instance the decision of whether to cook at home (direct energy in the household) or to go to a restaurant (indirect energy consumption outside the household). In total an average of 50 % of the total energy consumption over all sectors were related to direct household energy use in all three countries (Figure 8.7).

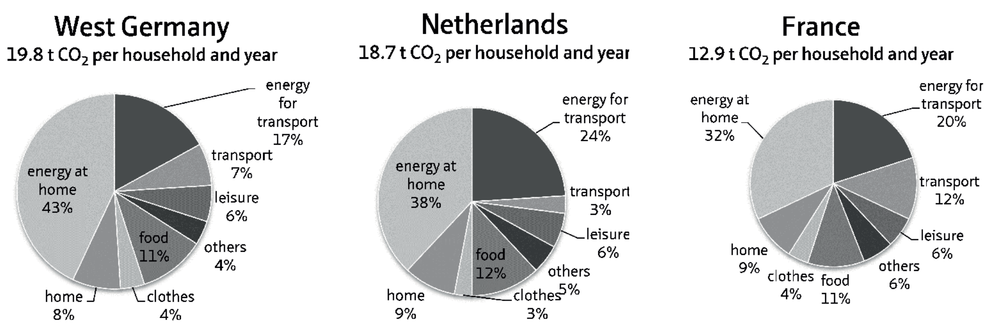

FIGURE 8.7 Comparison of total CO_2-emissions in West Germany, The Netherlands and France by consumption sectors (from Perrels & Weber 2000)

This means that to the directly measurable energy consumption in the house approximately the same amount can be added as indirect energy consumption. This is important to recognise since in this study only the direct household energy consumption is taken into the balance. Regarding the different household groups in the study the highest CO_2-emissions were caused by middle-aged (35 to below 60 years) families, whereas the lowest emissions were caused by households of young singles (below 35 years) (Figure 8.8). These are obvious results since the CO_2-emissions correlate to the number of persons in the household. More interesting is a comparison within one household category where other influence factors play a role.

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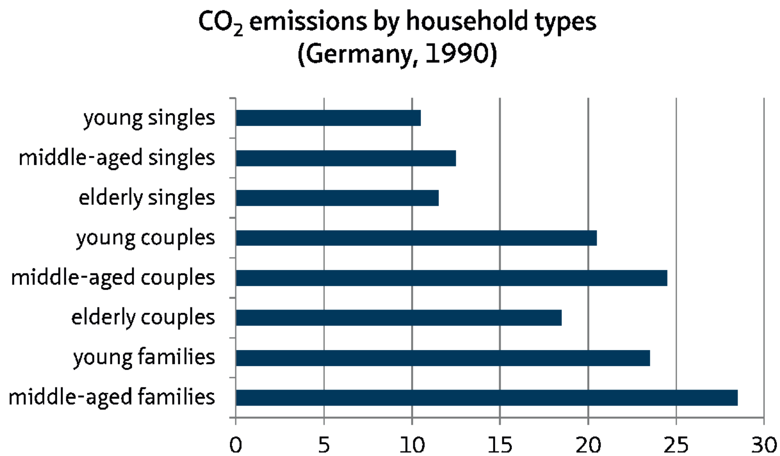

FIGURE 8.8 CO_2-emissions of different household types in Germany, from (Perrels & Weber 2000)

In the study the number of family members is two adults plus one or more children. If the household income would have been included in the differentiation, probably an even higher difference would have shown, because in this evaluation high and low-income households are grouped within one category. In an older study of Lutzenhiser & Hackett (1993) household income and housing situation (detached single-family house or multi-family apartments) were considered as well for the analysis of US private households. This study came to the result, that older families, living in a detached house with a high household income cause the greatest CO_2 emissions. At the other end of the scale they found the old singles, living in a multi-family house on a small income. The large differences could mostly be argued from the income aspects. In Europe the socio-demographic trend is an increasing number of single and couple households, which leads to a stable or slightly increasing number of households despite decreasing population. Since single and couple households consume more energy per person than households with more members the total energy consumption does not necessarily decline proportionally to the decreasing population.

Regarding the scenarios these effects can be represented in a certain correction factor for the different demographic groups in a community. This is helpful to target measures more precisely to the specific target groups and to come to a realistic energy-savings potential in the scenarios. It seems clear that the household type and income structure will have significant influence on the real energy demand and CO_2-emissions and on the energy efficiency and savings potentials. Since the demographic mapping of the community can be based on the household structures, the specific correction factors can be located and represented in a GIS.

§ 8.4.2 User-behaviour effects in the electricity and heating sector

The effects of different user behaviour on the patterns of energy consumption have been analysed in various studies (cf. Raaij & Verhallen (1983a), Schlomann *et al.* (2004), Paauw *et al.* (2009), Hacke (2009)). The energy demand of buildings is determined by several factors of which the total amount of heated living space is the important influence factor. Another important aspect is the individual habits of energy use.

While over the past years the energy consumption of the heating sector could be reduced by nearly 15 % due to higher efficiency standards for new buildings and modern heating technologies, the electricity consumption rose gradually by 16 % between 1990 and 2006, a trend which is representative also for the European context (OECD 2007). In their study Schlomann *et et al.* (2004) analysed the energy consumption of private households through over 20,000 questionnaires. They concluded that also the energy-savings in the heating sector should have been higher than the figures indicate. The heating energy demand fell with the age of the building but not as much as could have been assumed from the increased legal requirements. Schlomann *et al.* (2004) conclude that there obviously are strong demographic and behavioural effects that influence the energy demand for heating. Next to the shift towards single and couple households, the increasing living spaces per person add to the energy demand in the heating sector. While in the 1980s the average living space per person was approximately 35 m², today it is already at almost 42 m² per person. This increase in living space is not distributed evenly over the different household types. While the living spaces occupied by young families have remained fairly constant, the largest increase can be found in the living conditions of older couples. In single-person households the average living-space per person is much larger (62.5 m²) than in couple households (43.4 m²) and in family households (28.5 m²). The average living space is also influenced by the building typology. In single-family houses the average living-space is larger than in multi-family buildings.

Energy use behaviour is based on routines, which is often repeated habitual behaviour, that is, once learned, performed without much need for reflection and attention to it. This makes habitual behaviour difficult to change or even alter, because it is hardly performed consciously. From a psychological perspective there is a need to make these habits conscious in order to change or modify them. To alter everyday behaviour several conditions are relevant. According to Krömker (2008) these are belief in correlations, belief in cost-benefit proportion, general attitude, the ability to act and social norms. The first important aspect is the general understanding of the problem, for instance that much energy is lost through permanently open windows. Together with the cost-benefit consideration that also much money is lost by this ventilation strategy the attitude guiding the behaviour is formed. Therefore, knowledge about the connections

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and options is essential. Regarding the cost-benefit ratio, expensive efficiency measures significantly reduce the implementation even when the (long-term) benefit is high.

The energy demand for heating is determined mainly by the indoor air temperatures and the ventilation strategy. In both cases there are great deviations in all user groups. Regarding electrical appliances consumers take the first seminal decision when buying energy efficient or non-energy efficient appliances. This decision-making process is influenced by cost-benefit considerations and also by personal beliefs and environmental awareness. The everyday-use of appliances is largely influenced by convenience and comfort aspects. Paauw *et al.* (2009) have developed a user typology for heating and electricity consumption based on the dominating decision-making strategies of different household groups. This typology is based on the findings of Raaij & Verhallen (1983a) who analysed energy related attitudes and the relationships between these attitudes, home characteristics, socio-demographic aspects and the actual energy use behaviour. From these relationships they derived five energy consumption patterns for the heating sector (conservers, spenders, cool room high ventilation, warm room low ventilation, average) (Raaij & Verhallen 1983b). As indicated in Table 8.4 the cost aspect is dominant in all groups. The other drivers vary over the household types.

HOUSEHOLD TYPE	CONVENIENCE	CONSCIOUSNESS	COSTS	CLIMATE
Single	●○○○○	●●●○○	●●●●●	●○○○○
Two adults below the age of 60	●●●○○	●●●○○	●●○○○	●●○○○
Single parent family	●○○○○	●●●●○	●●●●○	●○○○○
Family /two adult and children)	●○○○○	●●●○○	●●●●○	●●○○○
Seniors above the age of 60	●●●○○	●○○○○	●●●●○	●●○○○

TABLE 8.4 Dominating behavioural drivers for different household types (from Paauw et al. 2009)

Connected to these preferences some typical behaviour strategies are connected (Table 8.5). The authors state that the typology still has to be verified. This is planned by a large number of interviews to verify the typology characteristics. The target is to build a model of user behaviour that can be assigned to energy systems planning.

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CONVENIENCE	CONSCIOUSNESS	COSTS	CLIMATE
Heating comfort heating	Heating intermittent comfort heating	Heating heating turned off where unnecessary	Heating first extra clothing Efficient heating and insulation
Hot Water comfort DHW production	Hot Water DHW on demand	Hot Water DHW on demand	Hot Water DHW on demand plus solar collectors
Ventilation tilted windows	Ventilation conscious natural ven-tilation mechanical ventilation on demand	Ventilation conscious natural ven-tilation mechanical ventilation on demand	Ventilation conscious natural ven-tilation
Lighting lighting for convenience	Lighting light turned off where unnecessary use of energy-saving light bulbs	Lighting light always turned off where unnecessary consequent use of ener-gy-saving light bulbs	Lighting use of energy-saving devices, energy-saving light bulbs, timers, solar lights.
Cooking convenience food, micro-wave preparation	Cooking good planning of food preparation, defrosting in fridge	Cooking cooking more meals at once one-pan meals	Cooking season-related products, not frozen one-pan meals
Electric Equipment all electric equipment on stand-by	Electric Equipment Frequently on stand-by	Electric Equipment off, when not in use Conscious buying of efficient equipment	Electric Equipment Conscious buying of efficient equipment only necessary equip-ment

TABLE 8.5 Behavioural typology of different categories, with central characteristics of energy use (cf. Paauw *et al.* 2009)

From the behavioural typology it becomes clear that in reality there is a large divergence between the categories. Nevertheless it seems worthwhile to take the preference typology into account, for instance when surveys and interviews are planned and to be aware that there are significant differences in the energy consumption patterns of the different user groups. When data is collected in the sector of individual energy behaviour and habits, the integration of a set of questions that allow a typological grouping will facilitate the monitoring of changes in attitudes, awareness and consciousness towards energy related topics.

§ 8.5 Conclusions

The default data for cross-sectoral energy system technologies is still scarce and mostly based on models and studies rather than demonstration projects. Especially for the load-shifting potentials in the power-to-heat sector the available studies are based on quite general statistics. The outcome of running field-tests and pilot studies will certainly help to make the data basis better. For all aspects that involve users, for instance for the willingness to comply with fluctuating electricity prices, acceptance studies are necessary to validate the assumptions. Despite the data situation most authors acknowledge high potentials in this field. For the case study of Wolfhagen the field test on the technical feasibility of Demand-Side-Integration and the acceptance of real-time-pricing signals is about to start. In 35 test households the acceptance and the load-shifting potential of surplus renewable electricity towards household appliances will be tested. Additionally two heat pumps in the field will hopefully contribute some data to potentials of power-to-heat strategies in Wolfhagen. Unfortunately the results are not available yet and the scenario model will have to be based on the data available from the cited studies.

For the implementation of small scale low-temperature heating grids a lot of data is available and numerous demonstrators show the feasibility. For the case study of Wolfhagen a feasibility study showed the potentials for the dense down-town areas. So far the motivation to invest in heat grids to increase the share of renewable energies in the heating sector is very low in the community of Wolfhagen. Here again it's not centrally technical restrictions and barriers that hinder the implementation must moistly political and technological priorities among the central stakeholders at the local energy service company and the communal government. Certainly the lack of existing best practice experiences limits the potential for future implementation. To achieve a transfer of experiences from the cited national and international projects in the field a new research project or a participation in a research project might be useful to fight scepticism.

To exploit the potentials of the technologies described in this chapter it is necessary to find pioneers. To find pioneers it is important to know something about the socio-economic architecture of the local population. In the case study of Wolfhagen a large number of conscious and motivated people can be found in the local residents' energy cooperative (Bürgerenergiegenossenschaft) that counts more than 740 members[49]. There is a high awareness among these persons for energy and mainly electricity issues. There might be a good potential for implementation of innovative sustainable

49 Info from Wilfried Steinbock (chairman BEG) on 16th of October 2015

systems if they can be convinced and integrated into the development process. The call for applications to participate in the field test showed a tremendous interest in the concepts of Demand-Side-Integration. The number of willing participants exceeded the available number of test households by far. These may as well be good recipients for innovative technologies in the context of a sustainable city system.

The local availability of data has shown to be a matter of persistence. Generally it can be stated that all the necessary data is available, somewhere. The data situation shows to be scattered for the case study in Wolfhagen which makes the collection very time consuming. Some data was not available because of data privacy. Nevertheless it is useful to specify the default data with local data wherever available. It has shown that at the different spots of competences there is a lot of specific knowledge about the specific local conditions. This knowledge is very valuable for the later the development of strategies and implementation of projects. The data collection phase can be used to build a network of competences for the later realisation. By specification of the data framework already important knowledge is gathered for the evaluation of scenarios.

9 Energy Transition Scenarios

"We are not predicting that a particular future will take place. [...] We do not believe that available data and theories will ever permit accurate predictions of what will happen to the world over the coming centuries. But we do believe that current knowledge permits us to rule out a range of futures as unrealistic."
Donella and Dennis Meadows in 'Limits to Growth – The 30-year update'

§ 9.1 Introduction

The previous chapters six, seven and eight represent the static data framework the next chapter will develop the development paths of the different sectors building environment, renewable energy and sustainable energy systems on a timeline. This is the core element of a scenario model 'What will happen, if a certain development takes place?' Scenarios can be helpful tools for decision-makers to elaborate and visualise a certain development path. The data framework which was described in the previous chapters is the starting point to think about developments to come. The possible development scenarios for energy transition in communities are manifold. Scenarios can be created for single development aspects, for instance the increase of photovoltaic installations or the use of public transport infrastructure if these are the only aspects to be analysed. Commonly, scenarios are used to evaluate the effects of complex system interactions, including different sectors and players. In addition to quantitative status-quo analysis and functional representation of key-actors and influence factors, the scenarios shall allow a careful peek into the future under given development conditions.

This chapter will cover two research questions: What principle scenario design is helpful to support communal energy transition processes? and What adaptations are necessary to make these general scenario design useful for the case study of Wolfhagen?

The chapter starts with a general description on the aims and the general structure of scenario modelling. For application in the case study, in Chapter ten, specific assumptions are defined. To show the principle working of the model, three basic scenarios, aside one business-as-usual scenario, are described. Each one focusses on one of the three main visions of communal energy transition from Chapter two. The first scenario assumes a maximum effort in energy efficiency. The second is focussed on a maximum production and utilisation of the local renewable energy potentials, with the aim to become a net-zero or plus-energy community. In the third scenario a high efficiency and a high development rate in renewables is combined with aspects of an improved connection between demand- and supply-side for both electricity and heating. This scenario comes closest to the ideas of exergy-thinking. The central aim of the scenarios is to make the effects of typical measures transparent for decision-makers. The interactions of different measures and the different energy sectors and their spatial effects are the key interest for the scenarios. The target groups are urban and energy planners in small- and medium-sized communities. The data framework and the model are tested and applied to the case study in Chapter ten.

These three examples shall prove the workability of the scenario modelling in general for the case study. In practical application the next step is to modify and differentiate the scenarios for different localities within the community boundaries or to differentiate in more technical detail. In a back-casting view necessary steps can be outlined and formulated into a roadmap to put the development paths into practical realisation. Scenarios are always only as good as the available data framework and as much as the key-factor interdependencies can be described. Therefore working with scenarios is about creating a continuous learning curve between developments that could be and realities that show.

§ 9.2 Methodology

The field of modern future studies, from which the methodology of scenario building origins, has a long tradition and encompasses many disciplines from military strategy (RAND Corporation, Herman Kahn and the Hudson Institute) to large-scale global scenarios on climate change (IPCC reports) or energy (IEA World Energy Outlook). Several publications address principle approaches to scenario building, for instance Amara (1981), Börjeson *et al.* (2005), Dreborg (2004), Carsjens (2009). Based on literature study principal scenario concepts are developed for the case study community of Wolfhagen. The scenario types reflect the typical approaches of the different aims and targets of scenario building and correlate to the different vision types described in chapter two. As support tools for communal decision-makers, scenarios shall give insight into the consequences of political course setting and general planning strategies. The overall picture is of greater interest than the detailed prediction for single measures in the system. The acquired data of chapters five to eight is used as the modelling basis in chapter ten. In this chapter the base-case scenario and the three scenarios for chapter ten are described. While chapter five gave a description of the past developments and the status quo in the case study community,

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chapters six, seven and eight collected the static data for the different measures such as the renewable energy potentials. This chapter collects the dynamic data assumed for the scenarios. The data is based on literature and the case study analysis. Assumptions on the development of the key parameters are presented to create the transparency to discuss the outcomes of the application in the final conclusions.

§ 9.3 What scenarios tell

It is important to differentiate between different methods of scenario building to create a real planning support for decision-makers. The high complexity of energy systems and the large number of rational and irrational influence factors create an environment where scenarios can be promising to anchor long-term goals in everyday planning practice. In principle scenarios can be differentiated in three basic approaches. In contrast to scientific simulation of more or less thoroughly describable mathematical problems, scenarios are commonly used to take a glimpse at future developments not fully foreseeable. Börjeson *et al*. (2005) differentiate scenarios according to the questions they answer and structure their scenario typology according to the questions they ask. "What will happen?" is asked by a predictive scenario type concerned with forecasting or timeline series. These scenarios are by nature focussed on a rather passive observation of possible developments. Not the effects of measures or alterations are the core questions but the extrapolation of trends and developments in the future. Börjeson *et al*. (2005) state that here often only single aspects are the objective of the modelling. An example from urban planning is the prognosis of demographic trends and age structure developments in the city. Next "What could happen?" scenarios focus on the factors affecting the behaviour of the system. They are called explorative scenarios. The factors under observation can be either external or internal. External factors can be defined as being outside the sphere of influence of the decision-makers, for instance the effects of climate change to local weather or urban climate conditions. Internal factors are parameters within the influence sphere of the decision-makers, as for instance the effects of enhanced refurbishment activities on energy consumption. For the focus of this thesis the strategic explorative scenarios are of greater interest, since alterations to the system occur from decision-making. Börjeson *et al*. (2005) emphasize that there is an overlap between typical "What-if" questions in the predictive scenarios and alterations made to key factors in the explorative analyses. A clear differentiation is not feasible since complex system models always include internal and external influence factors as well as forecasting or time series elements. The third principle type of scenarios asks the "What should happen?" question. The central difference to the first two scenario types is that here the final target situation defines the origin for the model. The interest of this type of scenario is to create a picture of the future situation as it should turn out and explore the necessary steps or barriers on the way. This procedure is also known as 'back-casting' approach. Regarding the degree of change that the future situation implies, the scenarios can be differentiated into models that only alter the internal factors of the existing system and models that allow entirely new system architectures with completely new rules and conditions.

The principle of thinking in three different modes about the future can as well be found in Dreborg (2004), who classifies future studies in a predictive, an eventual and a visionary mode of thinking. Similar approaches can be found in Amara (1981), Masini (1993) and Inayatullah (1990). To make practical use of scenarios they need to become implemented into the decision making process of the transition projects as a next step and undergo a translation process into definite steps of action.

Based on the approach of differentiating between predictions with limited scope and rather short-term perspective, strategic long-term planning and visionary description of desired future states, (Stremke 2010) creates a four-stepped approach to link the scenario process to project development (Figure 9.1). Although the procedure is based more in strategic planning theory and makes no explicit reference to scenario modelling, the bridge to the planning process is important to create an implementation environment.

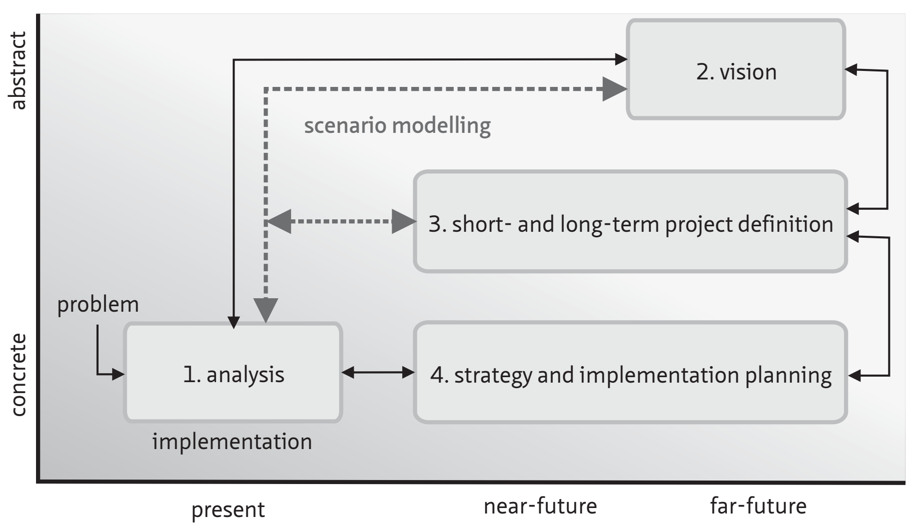

FIGURE 9.1 Scenario modelling may serve as analysis method within the four step planning approach to support transition projects (after Stremke (2010) and Albrechts (2004))

The scenarios may serve as modelling framework to analyse the effects of short- and long-term project implementation with regard to the formulated visions. Implementation strategies and the planning of implementation steps for the project are outside the scope of the scenario models. In the next sections the use of scenarios in the context of urban energy transition is elaborated. Geo-referenced scenarios and 'scenario-mapping' can provide important additional information and communication options.

§ 9.3.1 Scenario results as 'story tellers'

'What if..?' questions are core questions of strategic planning and typical for scenarios. Since energy systems involve many different technical and non-technical issues there is a high uncertainty about the effects of fundamental changes to the system. Energy projects consequently often trigger scepticism and opposition among the local residents. They often fear that the changes, once started, will negatively affect their direct communal environment and that there won't be much option to influence the direction of the course once started. Scenarios are therefore predominately tools for communication and may bridge the gap over the physical and economic systems poorly understood today (Kowalski *et al*. 2009). The results of scenarios to some extent illustrate what is already known about the systems of interest and how it may evolve under presumed conditions. The scenarios visualise the assumptions made and illustrate possible alternatives. Scenarios create some objectivity and a long-term perspective. Scenarios usually address developments over long time-spans into the future such as 20, 30 or even 50 years. They are therefore much about 'story-telling' about possible future developments and inspiration along the path to get there. Other than simulations, scenarios allow alterations along the way, for instance if influential boundary conditions change. For communal decision-makers scenarios create pictures of future options in their energy systems on which they may base more detailed project planning and step-by-step action. In a back-casting process the scenarios are important tools to show necessary steps and limitations. For communal decision-makers they help to avoid idealistic targets or to reason for fundamental decisions.

§ 9.3.2 Additional information from geographic scenarios

As has already been described in chapter four, the geographic reference gives additional information to quantitative calculations. For communal decision-makers the results are given in the frame of their planning authority. Results become more readable for non-energy experts. Most scenarios that effect energy systems have a strong correlation to spatial developments and conflicting use of available spaces. Here the geographic reference contributes with a better overview on the options and effects of developments. The visualisation in space illustrates well realistic and rather unrealistic options; especially for scenarios with a strong emphasis on either efficiency measures, for instance in building refurbishments or for the installation of renewable energy plants. For instance an increase in refurbishment rates from below one to more than three per cent of all buildings per year doesn't seem to be so much by mere figure. If the number of objects under refurbishment is then indicated randomly on a map, the enormous efforts that have to be taken to achieve these rates become visually clear. Based on maps, necessary or potential land-use changes become visible. This is central for any local biomass strategy, open-land solar plants or wind energy plants. Necessary spaces and the dimension of affected landscape become visible. At the same time the often exaggerated space demands of renewable energy plants can be put into proper perspective. Another important aspect is the factor of necessary transportation distances of waste energy and grid lengths for any heat or cold transportation. The distance between potential sources and consumers is crucial aside the mere quantitative potentials. One important aspect is taking energy potentials and opportunities to the 'front-door' of the local community. Locals get insight into the efficiency and renewable energy potentials within their direct influence sphere. This can be used to accelerate the implementation phase and to increase motivation.

§ 9.3.3 Boundary conditions and methodology of scenario building

The adequate methodology for scenarios depends on the scenario type and the intention behind modelling. Time-series of a limited number of aspects give a good overview about probable developments in predictive scenarios. These may be altered and combined with 'what-if?' studies that give insight in the development of parameters under changing conditions. As Börjeson *et al.* (2005) have stated, there is an overlap between predictive and explorative scenarios in this case. Bossel (2004) emphasises that any model represents the subjective selection of parameters and simplifications of the model builder. Therefore complex models cannot be proved right but only valid for the defined modelling purpose.

The timeframe for scenarios depends on the scope of the measures under study. Scenarios of climate change and demographic developments commonly encompass very long periods up to more than one-hundred years because only over long time-periods the behaviour of the system shows clearly. The scenarios of the latest report of the Intergovernmental Panel on climate change go as far as 2100 (Stocker *et al.* 2014). Scenarios based on the IPCC models therefore often adopt 2100 as far-future target (comp. WBGU 2003). Policy scenarios on energy transition usually focus not more than one generation ahead in their far-future scenarios. In most policy scenarios on energy transition the year 2050 is the furthermost target (European Commission (2011); Kelemen *et al.* (2009); Bundesregierung (2010)). Intermediate targets are defined for 2020, for instance in the EU '20-20-20' targets[50] (European Commission 2007). The year 2020 was adopted as intermediate near-future target by many scientific on political scenarios for energy transition (Bundesregierung (2007); Diefenbach *et al.* (2013)), although some studies as well defined the year 2030 as target year (Forum for the Future 2008). Within scientific publications on energy transition scenarios most often 2050 is taken as final year with interpolation values for the decades (Nitsch *et al.* 2012); FVEE 2011; Broersma *et al.* 2011). Stremke (2010) differentiates only between near- and far-future developments, which of course makes the approach less vulnerable to the elapse of time.

For this study I use the method of focussing on the year 2050 as final target year for creating far-future visions of the energy system. As well I create interpolation values for the years 2020, 2030 and 2040. Basically this is done to comply with the requirements of the research activity going on in the case study. Just as well the reference years may be read as very-close future (2020), near-future (2030), and far-futures (2040, 2050). It is important that there is reference to futures that can be overlooked by the decision-makers and that the scenarios reflect implementation periods. For each scenario the assumptions are given in the following sections. The intention of the scenarios described later on is not to make forecast on a complex future including all possible technologies. My intention is to create rather simplified scenarios with clear messages that facilitate decision making and communication.

§ 9.4 Scenarios for the Wolfhagen case study

The idea of energy transition can be addressed from different perspectives. This was shown in chapter two where different transition visions were elaborated. With the scenarios different strategies for the city of Wolfhagen shall be pictured to emphasise the effects of principle developments. As described in chapter five, the community has already started the transition process at different ends, for instance by different

50 With the climate and energy package of 2007, the European Commission published a set of targets on the energy supply in the year 2020. This was a 20% reduction in EU greenhouse gas emissions from 1990 levels, Raising the share of EU energy consumption produced from renewable resources to 20% and a 20% improvement in the EU's energy efficiency (see http://ec.europa.eu/clima/policies/package/index_en.htm)

energy-savings and efficiency initiatives and large-scale renewable energy production. To bundle the existing developments into thematic contexts I define three thematic scenario cases for possible future developments in the community. Additionally there is a base-case reference scenario representing a time-line study on current trends without specific emphasis on energy issues which extrapolates present trends into the future. Both the 'Energy Efficiency Scenario' and the 'Renewable Energies Scenario' represent rather typical "What-if" approaches. While scenario one and two represent mostly the explorative strategic scenario type, the third scenario is more speculative and represents options for long-term targets with alternative more synergetic energy supply structures. Here the question "What should happen?" gets greater emphasis than in the other two scenarios. While the scenarios one and two can be based on a quantitative calculation of demand and supply balances. The system complexity in scenario three is by far greater. To stay within the systematic the effects of a more synergetic local energy match is shown exemplarily.

In the following the assumptions for the four scenarios are given. The application of the data framework from chapters six, seven and eight the scenarios from this chapter are presented.

§ 9.5 Scenario 0 – Extrapolation of present trends

The scenario is meant as reference base-case. Only from the extrapolation of existing trends and development tendencies the results and possible improvements of other scenarios can be quantified and weighted. In this context the scenario 0 is not meant as the scenario where nothing is done. Since there are already existing initiatives and on-going developments in the energy system of the case study, the scenario is representing the 'business-as-usual' attitude of continuing on the existing paths. The scenario shows the development path without any extended efforts for energy transition on a communal level. Nevertheless, the development in Wolfhagen is dependent on the national strategies to some extent. This includes the national regulation and subsidy policy regarding energy-efficiency measures. To represent this some assumptions from the base-case policy scenario from Matthes *et al.* (2013) are adapted for the Wolfhagen boundary conditions. The central assumption is that the refurbishment rate remains at the low level assumed for today. For Wolfhagen specifically there will be an increase in vacancies in the historic town and village centres. The vacancies mostly affect the very old building type. Regarding the heating systems it is assumed that central boilers are replaced after their statistical life-span of 25 years. In the base-case scenario the efficiency of the boilers increases according to the state-of-the-art but not much above that. The electricity demand is assumed

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to remain stable, because increasing equipment in the households compensates efficiency gains of new appliances. The central measures addressed in the base-case scenario are summarised in Table 9.1.

SCENARIO TARGETS	MEASURE	PARAMETER
Follow present developments in the building sector	Building developments	Refurbishment rate
		Vacancies
	Heating system development	Heating system renewal
Display demographic effects	Population development	Total population
		Age structure

TABLE 9.1 Key targets and measures for the reference scenario

The base-case scenario assumes that the enthusiasm to tackle the full energy transition slowly fades from the political agenda. The city turns to other issues that are regarded more urgent, for instance financial consolidation, or politically more attractive, for instance the promotion of employment. At the same time interest groups opposing energy projects gain influence and force stakeholders to revoke energy development plans. As the public support for large-scale energy initiatives wears off the initiatives of the population are returning to investments in their direct vicinity. This means that measures in energy efficiency and renewable energy production have to be profitable directly on a one to one basis for individual measure. This makes the implementation of larger scale highly efficient technologies on the larger scale as for instance heat grids very difficult.

§ 9.5.1 Assumptions on the development in the building sector

For the development of the energy demand in Wolfhagen in the base-case scenario the present trend of a low rate of energy-efficiency refurbishments in the building stock is assumed to continue. Without further efforts to increase activity in this sector the assumption seems quite realistic, for instance because of the demographic effects on the building stock and the limited effect energy measures have on the building resell value in Wolfhagen. Refurbishments usually do not pay-back when buildings are sold. For the scenario the refurbishment rate is assumed to remain at approximately 0.8 % per year. Regarding the refurbishment efficiency only a level 1 refurbishment according to the assumptions in chapter six are assumed. For the scenario the measures are distributed randomly over the buildings that have reached the statistical time for refurbishment until the assumed total refurbishment rate is met. The procedure is the same as for the efficiency scenario, just the quantity and quality of the refurbishments are reduced. In the scenario it can be assumed that a significant overall change in urban morphology will not occur. This is mainly because of the very low construction rates over the past years, which have been at 0.8 % per year in a 10-years average. In the base-case scenario these buildings reach the mandatory legal standard. The building activity is assumed to remain constant in all scenarios.

The low refurbishment rate leads to an increasing refurbishment backlog. At the same time the backlog will accumulate in the most problematic and complicated buildings in the town and village centres. Here mostly historic buildings are located which often show an unfavourable structural situation, long-term vacancies and precarious economical boundary conditions of the house-owners. With increasing energy prices these buildings become less and less attractive investments for owners and land-lords. Business-as-usual in this context will probably lead to increasing problems to maintain a liveable and attractive environment and infrastructure in the old town and village centres for inhabitants and commerce. Declining attractiveness of the centres and decay of buildings are accelerating factors.

The average value of vacancies in residential buildings in Germany is 8 % according to Matthes *et al.* (2013). Aring *et al.* (2010) estimated a value of 14 % vacancies for the town centre of Wolfhagen at the time of the study. This high figure includes trade and service areas and is limited on the problematic town centre situation. It can be assumed that this is not a representative figure for the entire residential area in the town and districts at the moment. Nevertheless it shows where the development may go. In the base-case scenario it is assumed that vacancies rise from 8 % in 2010 to up to a total of 15 % in 2050.

Regarding the development of electricity demand, the base-case scenario assumes an average exchange rate of household appliances and electrical appliances in other sectors and a gradual improvement in energy efficiency. German households have a very good accoutrement in household appliances and an increasing amount of home entertainment and office equipment (ZVEI 2011; Statistisches Bundesamt 2013). In the base scenario it is assumed that the energy-efficiency improvements in the electricity sector by new appliances are compensated by increasing number of technical devices in the home entertainment and office sectors. The households are already well-equipped with large household appliances. For the case study the household appliances are assumed to have no significant increase because of the demographic trends.

§ 9.5.2 Assumptions on the development in demography

One important influence factor regarding the future energy system on a long-term perspective in the base-case scenario is the structural changes of the population. As has been described in chapter four the population in Wolfhagen has been declining over the past decades. This trend will most probably continue for the next decades as well (Figure 9.2) and is assumed for all the scenarios. This is because the focus of this thesis is mainly on energy issues and the question how energy transition may positively affect the population development is out of the scope of this project.

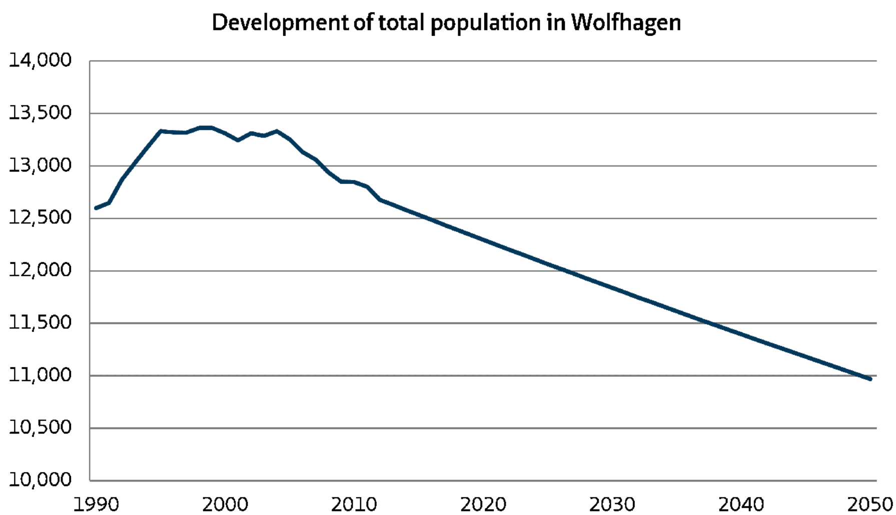


FIGURE 9.2 Development of the population in Wolfhagen over the past decades and prognosis (own calculation based on Hessisches Statistisches Landesamt (2012) and Hessisches Statistisches Landesamt (2010))

At the same time the average age structure of the population is shifting towards the older age classes (Figure 9.3). The demographic development for all scenarios bases on the statistical prognosis of the Hessen Agentur (HessenAgentur 2011). There are long-term forecasts for the community of Wolfhagen until 2030 available; the development until 2050 is extrapolated on the basis of the data of the regional developments (Hessisches Statistisches Landesamt 2010). This trend is also assumed for all scenarios.

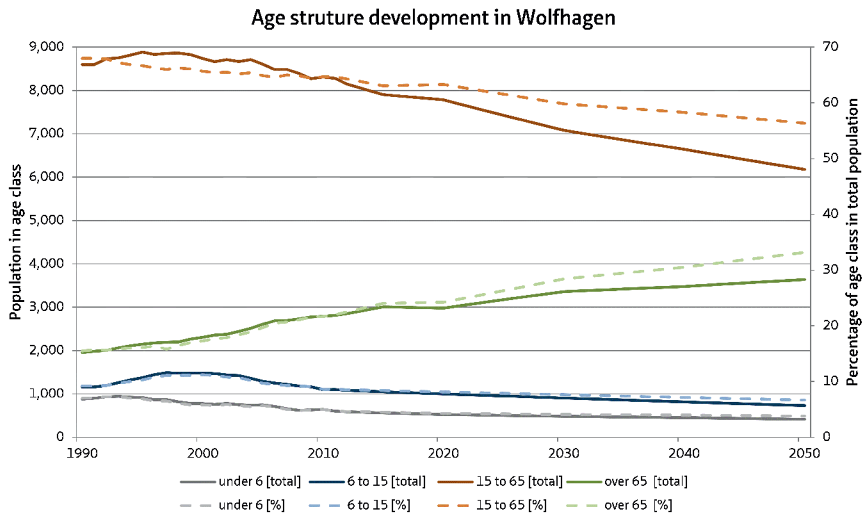


FIGURE 9.3 Age structure prognosis for the community of Wolfhagen (own calculation based on HessenAgentur (2011) and Hessisches Statistisches Landesamt (2010))

The prognosis is available for the entire community of Wolfhagen. The development of the city districts may deviate from the overall trend though. Regarding the developments in the different city districts there is no detailed statistical data available. For the scenario the population development is split according to the population statistic and the trends in the different city districts (Figure 9.4).

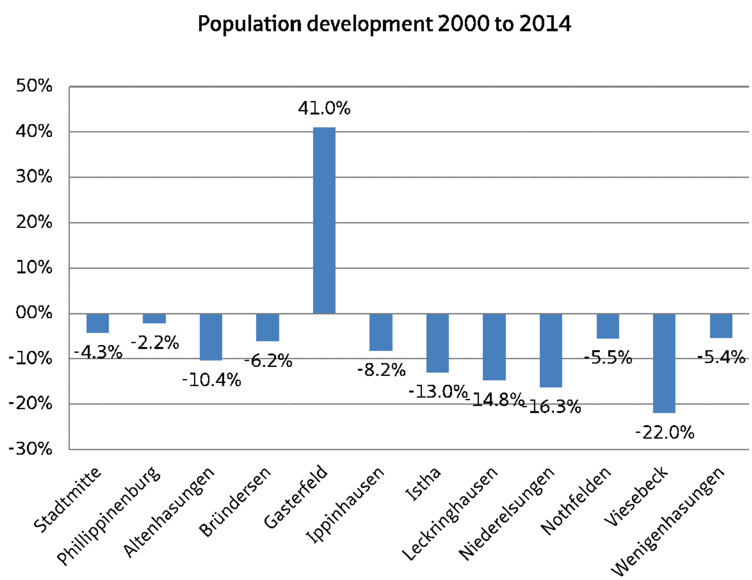


FIGURE 9.4 Population development 2000-2014

Regarding their relative development only one city district shows a positive balance of residents. This is because of the new facilities for refugees established in Gasterfeld in 2013. Without the refugees the trend is negative as well. Some districts show a very rapid decline. It is assumed that this is not a linear development but will slow down over the scenario period. The assumptions made for the population development for the scenarios are given in Table 9.2.

	2000 - 2014		2014 - 2020		2020 - 2030		2030 - 2040		2040 - 2050	
District	[%]	[total]	[%]	[total]	[%]	[total]	[%]	[total]	[%]	[total]
Wolfhagen (Stadtmitte)	-4.3	7,517	-2.8	7,307	-4.3	6,992	-5.0	6,643	-5.0	6,311
Philippinenburg / -thal	-2.2	175	-1.4	173	-2.6	168	-2.6	164	-2.6	159
Altenhasungen	-10.7	695	-2.2	680	-5.8	640	-7.1	595	-7.1	553
Bründersen	-6.2	640	-4.4	612	-6.0	575	-5.4	544	-5.4	515
Gasterfeld	41.0	392	10.0	431	-20.0	345	-3.0	335	-3.0	325
Ippinghausen	-8.2	1,071	-3.1	1,038	-4.2	994	-4.0	954	-4.0	916
Istha	-13.0	863	-5.0	820	-6.4	767	-5.2	727	-5.2	690
Leckringhausen	-14.8	46	-8.0	42	-8.8	39	-6.0	36	-6.0	34
Niederelsungen	-16.3	911	-12.0	802	-7.6	741	-7.4	686	-7.4	635
Nothfelden	-5.5	378	-2.0	370	-2.4	362	-2.4	353	-2.4	344
Viesebeck	-22.0	330	-10.0	297	-12.0	261	-6.0	246	-6.0	231
Wenigenhasun-gen	-5.4	510	-4.6	487	-4.4	465	-4.4	445	-4.4	425

TABLE 9.2 City of Wolfhagen, own calculations)

This means that despite the low efforts in energy efficiency and renewable energies the energy demand in Wolfhagen will probably decline because of declining population. These effects do not show proportionally though. The effects are shown in chapter ten. At the same time in this scenario the future development depends on trends other than energy transition.

§ 9.6 Scenario 1 – Energy Efficiency Improvement

The scenario focusses on the reduction of fossil energy demands for both heating and electricity. The focus is clearly on reduction strategies in the sectors of heating and electricity consumption. The central module of the scenario is the improvement of the existing building stock and household appliances. The central parameters are the refurbishment rates and the refurbishment efficiencies for both building envelope and heating systems and the strict replacement of inefficient appliances with top-runner models. In this scenario the central target figure is the final energy consumption not primarily the CO_2 emissions. This means that the scenario does not assume a large rate of change in energy carriers. This means that the existing boilers are replaced by systems with the same primary energy carrier. Because of the higher overall efficiencies it assumed that a large share of replaced boilers is equipped with solar thermal collectors for hot water production. The reduction in the household electricity is assumed according to the assumptions of the Energy Transition Scenario (Energiewendeszenario) in Matthes *et al.* (2013). This scenario as well assumes a strong support for the replacement of inefficient appliances by highly efficient alternatives and a stronger legal enforcement of energy-savings technologies. Although the 'soft-factors' of increased information and communication efforts can not directly be quantified, a change in user-behaviour is expected for the case study because of the high local priorities and continuous efforts in information and education during the project. This way re-bound effects in electricity consumption can be avoided. The central measures addressed in scenario 1 are summarised in Table 9.3.

SCENARIO TARGETS	MEASURE	PARAMETER
Reduction of energy demand for Heating and hot water production	Building refurbishment	Refurbishment rate
		Refurbishment efficiency
	Heating system improvement	Heating system efficiency
		Share of solar thermal
Reduction of energy demand for electricity in households	Appliance efficiency	Exchange rate
		Exchange efficiency

TABLE 9.3 Key targets and measures for the energy-efficiency scenario

The refurbishment of the building stock towards high energy efficiencies is a continuous process of great practical variety. The assumption that the community will focus mainly on efficiency measures means that the monitoring of the realised savings is quite difficult in practice. Since the strategy of the scenario involves the maximum number of individual decision-makers, a great emphasis has to be laid upon information and communication aspects. The scenario targets may conflict to some extent with the demographic development, since it can be assumed that an aging and shrinking population will significantly loose interest in long-term efficiency investments. Partly refurbished objects need a continuous refurbishment plan to achieve the targets over a longer period of time. The scenario will not show a significant effect on the modal split in energy carriers; since the demand reduction is the prime criterion and changing of primary energy carriers are not encouraged explicitly. There is a certain risk of rebound-effects in the electricity sector with increasing communication and entertainment equipment and the age group of 'internet-natives' growing up. The same applies for the building sector in the case of very old so far un-refurbished buildings in which refurbishments commonly lead to a significant increase in indoor thermal comfort and heating intensities. These effects cannot be verified in this model because of the typological data architecture which does not represent measured consumption data.

§ 9.6.1 Assumptions for heating demand reduction

The scenario assumes a continuous concerted initiative of the city of Wolfhagen and the local utilities to reduce the fossil energy demand in heating and electricity consumption. The city funding and incentive programmes are focussed primarily on the reduction of energy consumption by building refurbishments and improvements in the heating systems. The energy-efficiency scenario may as well serve as a reference scenario under the precondition of a strong public opposition against large-scale renewable energy plants and an unfavourable incentive development under the amendment of the Renewable Energies Act. The efficiency measures represented in this scenario include energy-efficiency measures in the building envelope, the heating system and in the sector of electricity appliances in private households.

It is assumed that with the start of the project in 2010 both the refurbishment rate and the refurbishment efficiency are constantly increased by the taken measures and information campaigns. The distribution of refurbishments follows no specific agenda, but is spread proportionally over the different building types and building ages. The scenario assumptions for the building sector can be found in Figure 9.5. The figure shows examplarily the distribution of the assumed improvements and the improvement level in the building sector. The renovation activity is distributed according to the absolute quantity of building area and the building age. Buildings of the construction period between 1958 and 1968 amount to the largest share of building space in Wolfhagen. Most renovation activity is foreseen here. Buildings constructed after 2002 will most probably not be refurbished until they reach a certain age, so there is no renovation activity assumed for these building until 2020. The distribution of the refurbishment activity over the total building stock is given in percent in light blue and in square meters (per decade) in dark blue.

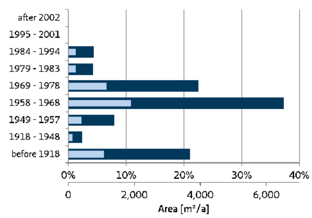
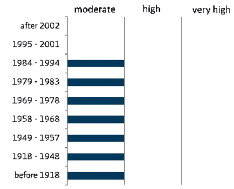
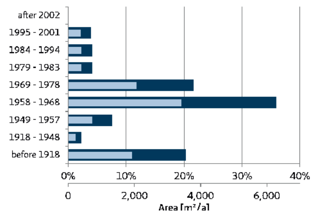
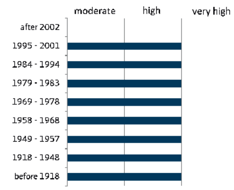
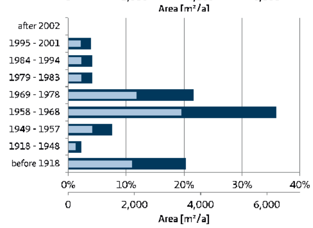
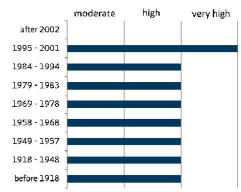
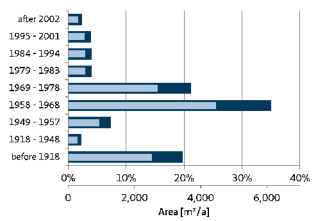
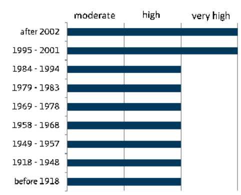
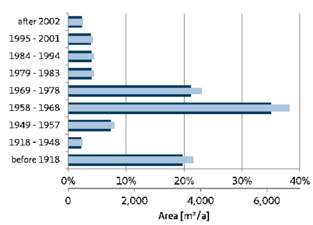
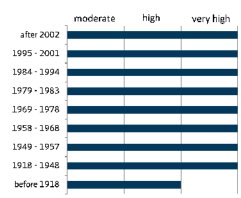
Scenario timeframe	Refurbishment rate	Refurbishment distribution by building age	Refurbishment efficiency by building age
1990 - 2010	0.8 %		
2011- 2015	1.5 %		
2016- 2020	1.5 %		
2021- 2025	2.0 %		
2026- 2030	3.0 %		

FIGURE 9.5 Assumptions on refurbishment rates and refurbishment efficiencies for the efficiency scenario

The scenario model includes the fact that floor area which has been refurbished in early years returns into the refurbishment cycle after a certain period of time. It is assumed that the entire area of residential space is fully refurbished again after 30 years. This means that the spaces refurbished in 1990 are up to refurbishment again in 2020.

At the same time the level of efficiency increases over the time-span of the scenario because of technical improvements and higher legal recommendations.

In practice many building owners commonly stretch their refurbishment activities over longer periods of time as indicated in Figure 9.6. Specific occasions are used to improve the energy efficiency step by step. To include these effects would mean too much detail to be represented in the scenario model for this thesis. Nevertheless it is important for decision-makers to find ways to support long-term strategies with specific incentives and knowledge support to ensure the overall refurbishment rates.

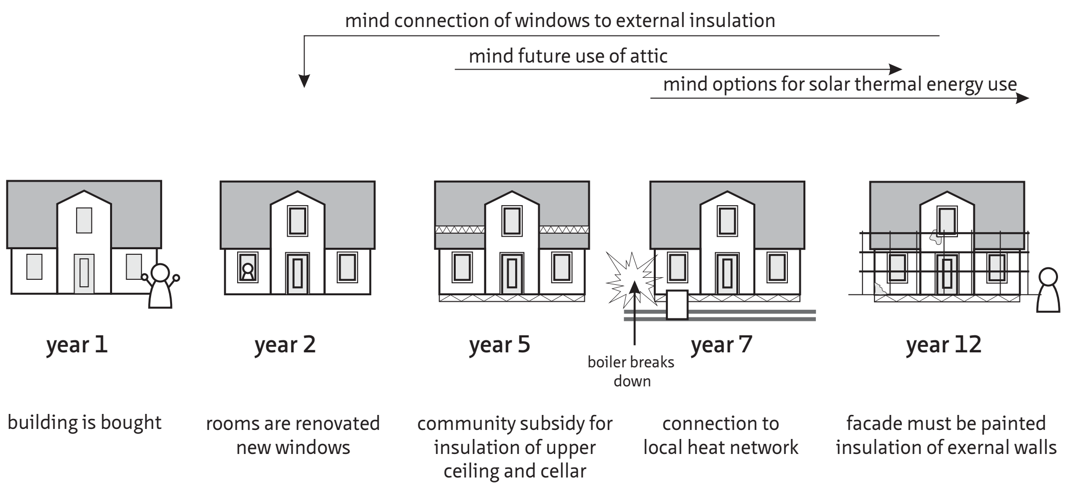


FIGURE 9.6 Refurbishments are often stretched over longer time-periods

In the efficiency scenario, the exchange rates of heating systems are based on the assumptions of Matthes *et al.* (2013) for the “Energiewendeszenario”. Matthes *et al.* (2013) assume the exchange rate of boilers in Germany to be below 4 % per year at the moment. For the base-case scenario 3 % exchange rate are assumed. For the efficiency scenario it is assumed that the exchange rate can be raised to 5 % per year in compliance with Matthes *et al.* (2013). The efficiency gain due to a new high-efficient boiler is assumed according to LEE & GEF (2009) with additional 8.8 % if the building is refurbished and according to BDH (2011) with 25 % if only the heating system is modernized. For 50 % of all new installations a solar thermal system is assumed, which affects mostly the CO_2-emissions. It is assumed that in the efficiency scenario from the year 2015 on there are no new standard boilers for oil or gas to replace old boilers and that there are no new gas or oil condensing boilers installed without additional solar thermal plants. This means that in the efficiency scenario there is a shift from old inefficient boilers towards new highly efficient boilers with solar thermal support. There is no significant shift towards a change in energy carriers foreseen in this scenario. This means that the split between the energy carriers remains the same as in the base-case scenario. An overview on the shift rates for the efficiency is given in Table 9.4. The table indicates what boiler technologies are used to replace the old boilers. From 2030 on there will be no more new low temperature boilers installations. Only condensing boilers with solar support are replacing old boilers. In this scenario no additional alternative technologies are assumed, this is why all values except for oil- and gas-boilers are zero.

RESIDENTIAL BUILDINGS	STOCK	2010	2020	2030	2040	2050
Oil condensing boiler	50	12.5 %	12.5 %	0 %	0 %	0 %
Oil condensing boiler + solar	45	12.5 %	12.5 %	50 %	50 %	50 %
Oil low-temperature boiler	507	25 %	25 %	0 %	0 %	0 %
Oil constant temperature boiler	1,298	0 %	0 %	0 %	0 %	0 %
Gas condensing boiler	129	12.5 %	12.5 %	0 %	0 %	0 %
Gas condensing boiler + solar	129	12.5 %	12.5 %	50 %	50 %	50 %
Gas low-temperature boiler	147	25 %	25 %	0 %	0 %	0 %
Gas constant temperature boiler	384	0 %	0 %	0 %	0 %	0 %
Electric heat pump	36	0 %	0 %	0 %	0 %	0 %
Micro-CHP stirling	1	0 %	0 %	0 %	0 %	0 %
Biomass boiler	825	0 %	0 %	0 %	0 %	0 %
Direct electric heater	36	0 %	0 %	0 %	0 %	0 %
Sum	3,587	100 %	100 %	100 %	100 %	100 %

TABLE 9.4 Overview on shift-rates in the efficiency scenario (own assumptions based on Matthes et al. 2013)

§ 9.6.2 Assumptions for electricity demand reduction

In the efficiency scenario efforts are made in the electricity sector as well. It is assumed that by enhanced information, mostly by the local utilities flanked by the local energy agency, a better consciousness can be created on the issues of energy-savings in the households. For the scenario the target figure of a yearly two per cent decline in the total electricity demand of the households is assumed. This can be regarded a realistic assumption according to available estimations on electricity savings potentials in households from Matthes *et al.* (2013) and BDEW (2013). It has to be stated though that the available data on differentiated electricity consumption deviates and is not consistent. For the purpose of this thesis I will therefore use a simplified quantitative approach.

§ 9.7 Scenario 2 – Energy autarchy on renewables

In contrast to the efficiency scenario, this scenario gives the production of renewable energy a high priority above energy-savings measures to achieve a 100 % local renewable production for electricity and heating by 2050. This means that with regard to refurbishments and energy-savings the assumptions of the base-case scenario are used. The scenario two concentrates on the development of renewable energy plants and the optimised exploitation of renewable energy sources within the communal boundaries. Therefore the prime focus is on available and exploitable energy resources from solar, wind and biomass. And consequently the scenario takes a stronger focus on the electricity sector. For this scenario the wind energy plants on the Rödeser Berg are in operation and for other sites re-powering is assumed. The photovoltaic plant development is enforced beyond the current trends which are already above national average. Also the options to use local biomass both for heat and electricity production are explored and exploited wherever feasible. The target of the scenario is to create a calculated autarchy on local renewables on a yearly basis. The balance between production and demand is regarded the prime criterion for the scenario. The CO_2 emissions are the key environmental indicator. Energy-efficiency measures are not dominating the scenario's implementation strategies, building refurbishments and improvement are assumed similar to the base-case assumptions, and so are the demographic developments. To reach a net-zero balance, there can an energy trade-off with the adjacent communities. The achieved energy autarchy is based on a levelled energy input and output balance. There is no explicit focus on technical autarchy but the scenario shows the options and consequences of a 'zero-energy-community'. The key targets and parameters are given in Table 9.5.

SCENARIO TARGETS	MEASURE	PARAMETER
100 % local renewable electricity production	Development of renewables	PV energy production
		Wind energy production
100 % local renewable heat production	Change of energy carriers	Solar thermal systems
		Biomass heating systems
		Geothermal heating systems

TABLE 9.5 Key targets and parameters for the renewable energies scenario

To achieve the goal, the heating sector needs to be shifted from fossil energy carriers towards renewable energies as well. Here the priority is on solar thermal and biomass according to the local potentials. Geothermal potentials are exploited as well but to a smaller extent.

§ 9.7.1 Assumptions for 100 % renewable electricity production

Regarding the PV development, Wolfhagen has had a rapid exploitation of photovoltaic sites since the year 2001. In average the installed PV-capacity between 2001 and 2012 has increased by 80 % yearly (Figure 9.7). This is because of the installation of several large-scale photovoltaic plants in Wolfhagen.

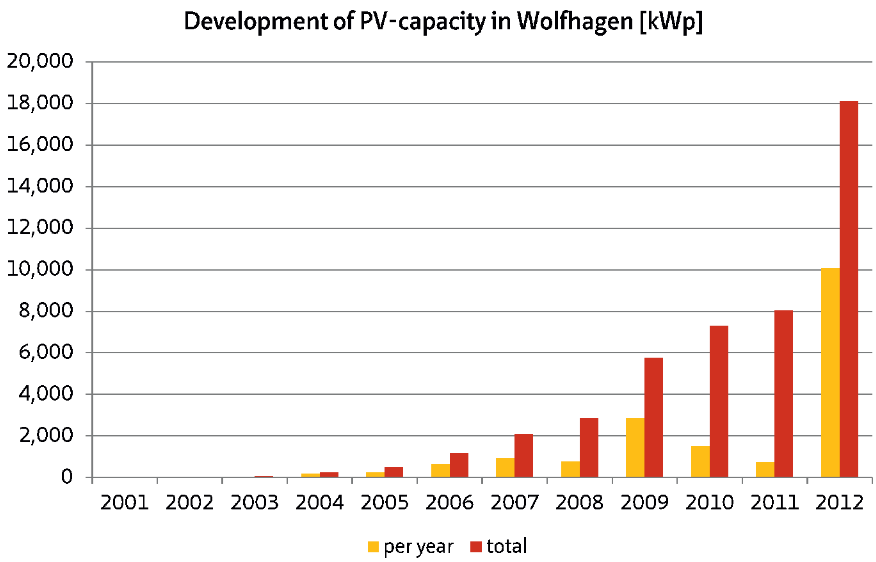


FIGURE 9.7 Development of PV-installations in Wolfhagen 2001 to 2012

It can be assumed that the development will slow down significantly in the coming years. The development rates for the renewable energy scenario are assumed according to Table 9.6. In this scenario a continuous development of PV capacities is foreseen. As shown in chapter seven the roof-top potentials for further PV-installations are still large and will not be fully exploited with the assumed development rates. To enable the installation of solar thermal plants as well to cover the open gap in renewable heat, only 50 % of the roof-top potentials are assigned to PV-installation. In the renewable energies scenario only the south-oriented roofs are used. For a system optimisation in the electricity grid, PV-installation on east- or west-oriented roofs can be favourable for load-smoothing. In the scenario no more large-scale open-land PV-installations are assumed.

[% PER a]	2010 - 2015	2015 - 2020	2020 - 2030	2030 - 2040	2040 - 2050
development rates of PV capacities	36	15	10	10	5

TABLE 9.6 Assumed development rates for PV-installations in Wolfhagen

To achieve the targets for the households the currently exploited wind energy sites on the 'Rödeser Berg' will be sufficient to supply the electricity demand on a yearly basis. If the large-scale consumer VITAQUA with a yearly demand of 27.5 GWh is left out of the balance there is already a positive result for the renewable electricity production in Wolfhagen (Figure 9.8, Figure 9.9). In the calculations without VITAQUA the remaining demands for industry, trade and service are still included.

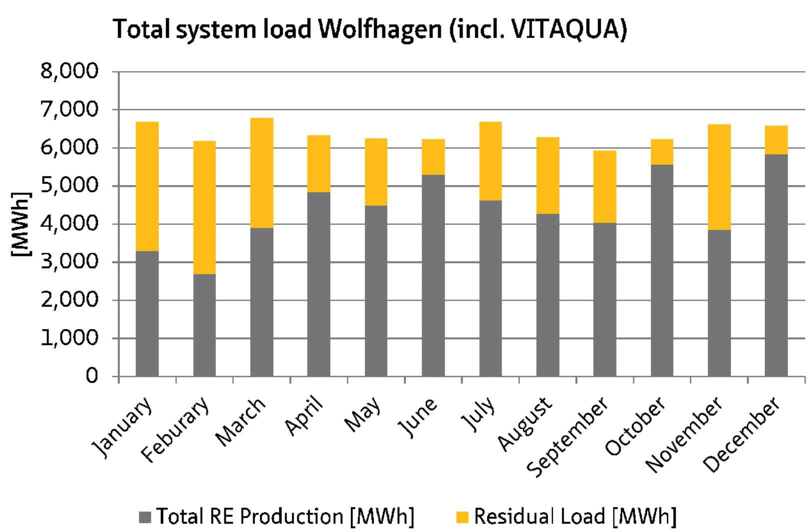


FIGURE 9.8 System load including VITAQUA

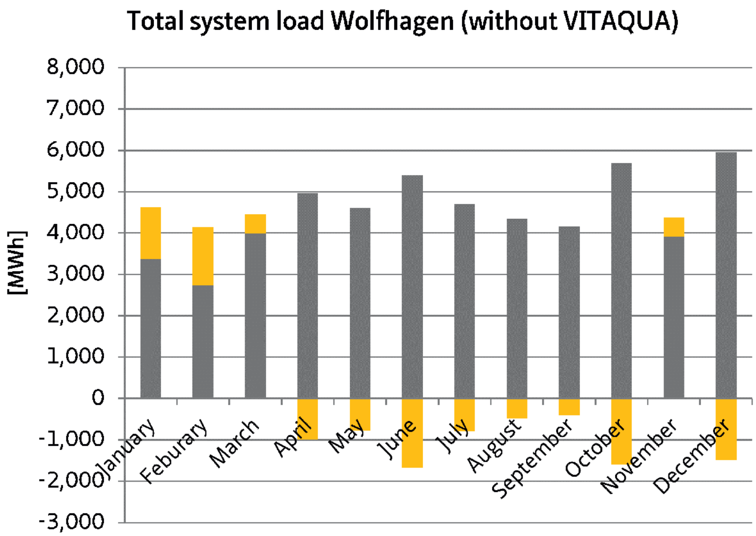


FIGURE 9.9 System load without VITAQUA

For the city of Wolfhagen the development of the 'Rödeser Berg' wind energy site is the maximum development of new large-scale wind energy. Future developments may be still increased in the sector of small-scale wind energy. The seven wind energy plants of the wind park Istha which are located within the Wolfhagen boundaries were re-powered in 2007 with 800 kW ENERCON plants and can be regarded state-of-the-art for the local moderate wind situation. Assuming a minimal operation time of 20 years, a repowering will be probable not before 2030. For the renewable energies scenario it is assumed that the wind park Istha will remain in operation until 2050 without significant changes in capacity. There is no data available on existing small-scale wind energy in Wolfhagen. It is assumed that the total capacity does not exceed 55 kW. The future installation of small-scale wind energy is assumed to remain a niche application without much development dynamic (Table 9.7).

[% PER year]	2010 - 2015	2015 - 2020	2020 - 2030	2030 - 2040	2040 - 2050
development rates of wind capacities	100	10	10	5	5

TABLE 9.7 Assumed development rates for small-scale wind energy in Wolfhagen

For the renewable electricity development the key potentials are in additional PV capacities. Some more potential in the electricity sector can be exploited in combination with the heat sector if the potentials for biomass CHP-plants are further developed. In the renewables scenario there are no new energy grids assumed. The CHP plants are assumed as micro-CHP plants based on either wood-chips or firewood for single buildings or small ensembles like farms.

§ 9.7.2 Assumptions for 100 % renewable heat production

In the renewable energies scenario, the exchange rates of heating systems are based on the assumptions of Matthes *et al.* (2013) for the 'Energiewendeszenario'. It is assumed that from the year 2020 there will be a significant shift from fossil-fuelled heating systems towards heating systems based on solar energy, geothermal energy and biomass. All fossil fuel boilers which reach their lifespan are replaced by renewable heating systems. Since the refurbishment rates at the same time are kept at the base-case level, there is a trend towards biomass heating systems assumed. This is because biomass systems can supply the necessary high system temperatures of buildings with high specific demands. Biomass heating is combined with solar thermal energy or used in micro-CHP. Because of the increase in photovoltaic and wind energy there can be a shift in heating systems towards electric heating systems as well to use surplus electricity. These systems are assumed direct electric heating systems and hot water boilers mostly. In this scenario a continuous shift towards local renewable energy carriers is assumed for heating and domestic hot water production. An overview on the assumed shifts in heating technology is given in Table 9.8.

RESIDENTIAL BUILDINGS	STOCK	2010	2020	2030	2040	2050
Oil condensing boiler	50	0 %	0 %	0 %	0 %	0 %
Oil condensing boiler + solar	45	25 %	0 %	0 %	0 %	0 %
Oil low-temperature boiler	507	0 %	0 %	0 %	0 %	0 %
Oil constant temperature boiler	1,298	0 %	0 %	0 %	0 %	0 %
Gas condensing boiler	129	0 %	0 %	0 %	0 %	0 %
Gas condensing boiler + solar	129	25 %	0 %	0 %	0 %	0 %
Gas low-temperature boiler	147	0 %	0 %	0 %	0 %	0 %
Gas constant temperature boiler	384	0 %	0 %	0 %	0 %	0 %
Electric heat pump	36	15 %	25 %	30 %	30 %	30 %
Micro-CHP stirling	1	5 %	10 %	10 %	10 %	10 %
Biomass boiler	825	25 %	50 %	45 %	40 %	40 %
Direct electric heater	36	5 %	15 %	15 %	20 %	20 %
Sum	3,587	100 %	100 %	100 %	100 %	100 %

TABLE 9.8 Overview on shift-rates in the renewable energies scenario (own assumptions based on Matthes et al. 2013)

For the few new buildings in Wolfhagen a positive energy balance is mandatory, meaning that only plus-energy concepts are being built.

To reach full balance on demand-supply also for the heat sector the biomass potentials are exploited and an energy carrier shift towards heat pumps is necessary which will lead to an increase in electricity demand in the community. To achieve the goal of 100 % renewables in heating surplus electricity is accounted to make up deficits in renewable heat supply. This is necessary to bridge the long refurbishment periods. It is assumed that renewable electricity could be used one to one for heating. This certainly means no true energy autonomy but comes closest to the target of a net-zero or plus-energy community similar to net-zero or plus-energy building concepts.

§ 9.8 Scenario 3 – Smart city synergies

The scenario is meant to focus primarily on an improved local match of demand and supply structures. This scenario follows the ideas of low-exergy thinking and smart synergies to make maximal use of the locally available energy potential. For the renewable electricity integration the scenario concentrates on the options to achieve a better matching in time between renewable production and demand. The technologies of interest are Demand-Side-Integration and Power-to-Heat concepts. For the heating sector local small- and medium-scale heat grids are interesting; mainly to take the situation of greater disparities in energy (and temperature) demand into account. The central idea is to create smarter connections between different demand and supply clusters and to dimension energy production on the existing demand. This approach can be regarded a 'one-step-further' approach to the maximisation of renewable capacities in scenario two. The scenario focusses on local optimisations rather than the quantitative net-zero balance. For the electricity sector this means that a strong effort is put into a temporal match of renewable supply and local demand. This means that a broad introduction of Demand Response is necessary for all flexible household appliances. To increase the capacity of flexible local loads, heat pumps in combination with heat storage become increasingly important to shift renewable energy from the electricity sector to the heating sector. The advantage of thermal processes and storage for the purpose to use surplus electricity is their availability and their low costs. Power-to-heat concepts contradict the primary idea of exergy thinking. This issue will be discussed in the conclusions in chapter twelve.

The correlating measures that the city of Wolfhagen takes to improve the refurbishment activity and to maintain a sustainable development in the city structures include a strong focus on inner city developments rather than new constructions on the outskirts since high-density mixed quarters offer more options for optimised energy supply and demand. In this context the development of local heating networks is a possible option for sustainable re-development. To stop urban sprawl and the thinning of the centres, many rural communities have agreed upon a strategy to shift towards a stronger development of inner city derelict plots and undeveloped areas within the town rather than the development of new settlements on the town borders. For the smart-city scenario the development of small- and medium-sized heating networks is assumed. They origin mostly from either dense demand structures in the town centres or from favourable supply situations for instance from semi-central biomass or biogas plants. The key targets and measures to improve the local matching are given in Table 9.9.

SCENARIO TARGETS	MEASURE	PARAMETER
Optimisation of local electricity production and consumption	Demand Side Integration	Heat Pumps and Appliances
		Power-to-Heat rates
Optimisation of local heat production and consumption	Heating networks	Heating network development
		Cascading and storage

TABLE 9.9 Key targets and parameters for the smart cities scenario

§ 9.8.1 Assumptions for local electricity optimisation

As indicated in the renewable energies scenario the community is able to generate a surplus in renewable electricity already if the large-scale consumer VITAQUA is left out of the balance. The renewable electricity potential for the scenario is given in Table 9.10. For the smart-city scenario not only the quantity of surplus renewable production is important but also the time-correlation of production and demand. The scenario assumes the same development rates for renewable electricity production as scenario two. Additionally the target is to reduce import and export transfers of electricity to a minimum. For this it is necessary to increase the flexibility of electricity consumers in households as much as possible to adapt the demand to the fluctuating supply.

	RESIDUAL LOAD [MWh]	TOTAL SYSTEM LOAD [MWh]	SURPLUS HOURS [h]	DEMAND HOURS [h]	SURPLUS HOURS [%]
January	1,256.50	4,625.54	234	510	31 %
February	1,412.47	4,149,83	171	501	25 %
March	470.93	4,149.82	246	498	33 %
April	-985.28	3,978.76	380	340	53 %
May	-779.65	3,832.84	374	370	50 %
June	-1,672.78	3,729.15	435	285	60 %
July	-794.06	3,904.01	358	386	48 %
August	-478.09	3,861.93	356	388	48 %
September	-406.24	3,746.73	345	375	48 %
October	-1,594.90	4,092.08	472	272	63 %
November	467.93	4,386.67	263	457	37 %
December	-1,489.70	4,469.98	441	303	59 %
Total	-4,592.87	49,240.32	4,075	4,685	47 %

TABLE 9.10 Distribution of renewable surplus (data 2013, including wind park, without VITAQUA)

There are no consistent assumptions on the future potential of Demand-Side-Integration. For the German situation the most elaborated studies are by Stadler (2006), Klobasa (2007), Roon *et al.* (2010) and dena (2012). These are also the basis for the more detailed calculations of Apel *et al.* (2012). All studies regard the households to show the largest potentials for a load adjustment in the electricity sector. Apel *et al.* (2012) use a model region approach and a sensitivity analysis to model the load shifting potential for Germany. Klobasa (2007) gives a more differentiated estimation on load shifting potentials in households. He assumes an averaged load shifting potential of 72 kWh per household and month from household appliances. Additionally there is a regulation potential from hot water production and heat pumps, which is considered in the heating sector. For the scenario it is assumed that the number of households participating in the Demand-Side-Integration increases by 10 % per year as indicated in Table 9.11.

NUMBER OF HOUSEHOLDS WITH DSI	2010	2020	2030	2040	2050
Households	50	100	200	400	800

TABLE 9.11 Development of Demand-Side-Integration in households

This development rate lies above the assumptions by Matthes *et al.* (2013) but could be realistic regarding the strong local interest in the issue and the disproportionate growth of renewable compared to national prognosis.

In the smart-city scenario, the exchange rates of heating systems are based as well on the assumptions of Matthes *et al.* (2013). It is assumed that from the year 2020 in this scenario there will be a strong shift from fossil fuelled heating systems towards heating systems capable to operate in a 'power-to-heat-mode', meaning that heat pumps and hot water storage system s replace more unfavourable systems. Because of the higher focus on electricity consumption and the broad implementation of smart-meters, a growing consciousness for energy-saving in electricity is assumed. For the smart-city scenario therefore the energy-saving developments of the efficiency scenario are assumed.

§ 9.8.2 Assumptions on heat optimisation

To contribute to the Demand-Side-Integration the domestic hot water production is continuously transformed towards thermal storage systems. For single-family houses a thermal storage tank for hot water production of 200 litres is assumed. The domestic hot water system is changed in combination with the heating system. Thermal storage systems are assumed to be implemented in combination with all decentral heating systems. In the smart-city scenario it is assumed that there will be a stronger shift towards heat grid solutions to optimise the local exergy efficiency in the heat supply. In this scenario the district heating is assumed to be supplied by decentral biomass CHP plants. Since there are almost no existing heat grids in the case study at this time, there is some development potential starting from a very low level though. Especially interesting are heat grids for the redevelopment of the dense old town centre. The potentials were analysed by Stroh (2013). According to the analysis the priority for the development of a local heat grid is given to the town centre as described in chapter seven. Some additional more detached grids are foreseen in the neighbourhoods of biogas CHP plants. The total shift of heating systems is given in Table 9.12.

RESIDENTIAL BUILDINGS	STOCK	2010	2020	2030	2040	2050
Oil condensing boiler	50	0 %	0 %	0 %	0 %	0 %
Oil condensing boiler + solar	45	25 %	0 %	0 %	0 %	0 %
Oil low-temperature boiler	507	0 %	0 %	0 %	0 %	0 %
Oil constant temperature boiler	1,298	0 %	0 %	0 %	0 %	0 %
Gas condensing boiler	129	0 %	0 %	0 %	0 %	0 %
Gas condensing boiler + solar	129	25 %	0 %	0 %	0 %	0 %
Gas low-temperature boiler	147	0 %	0 %	0 %	0 %	0 %
Gas constant temperature boiler	384	0 %	0 %	0 %	0 %	0 %
Electric heat pump	36	15 %	35 %	35 %	40 %	40 %
Micro-CHP stirling	1	5 %	15 %	10 %	10 %	10 %
Biomass boiler	825	25 %	20 %	20 %	15 %	15 %
Direct electric heater	36	5 %	20 %	15 %	15 %	15 %
Local district heating	0	0 %	10 %	20 %	20 %	20 %
Sum	3,587	100 %	100 %	100 %	100 %	100 %

TABLE 9.12 Overview on shift-rates in the smart cities scenario (own assumptions based on Matthes et al. 2013)

The dominating heating system in the smart-city scenario is the heat pump. Since heat pumps operate best in refurbished buildings which require low supply temperatures, building refurbishment is a precondition to an optimal integration of heat pump systems. For the smart-city scenario the refurbishment developments of the energy-efficiency scenario are assumed to provide good boundary conditions for the technology shift. For the development of district heating grids the building efficiency is not quite as important. This makes the local district heating a feasible solution for the clusters with a high density of historic buildings with limited efficiency potentials. The mixed structures of the dense inner city clusters allow an optimised supply of buildings with different supply temperature demands. It is assumed that the refurbished buildings with low temperature demands can be connected to the return-line to enhance the overall exergy efficiency.

§ 9.9 Conclusions

The central research questions of this chapter were what principle scenario designs may help communal decision-makers to initiate and support energy transition processes and what adaptations to the general scenario designs were necessary for the application in the case study. It could be shown that scenarios are most helpful when they allow a targeted view into future developments. To get clear tendencies the number of parameters and influence factors should be limited. Popular scenarios are mostly explorative scenarios and ask typical "What-if" questions. For communal decision-makers these scenarios are most helpful for the moderation and decision making process. Also back-casting approaches are useful in combination with a development vision for the community. The imaging character of GIS systems offers additional benefits for the spatially sensitive developments in renewable energy planning, spatial impacts and system optimisation. The SREX project has shown many options for representation and envisioning of development scenarios towards sustainable energy supply (Broersma *et al.* 2011). For small communities as the case study community in Wolfhagen the total number of options and technologies in this thesis is consciously limited to the most significant modules. This is to make the story or message of the scenario as transparent as possible. This means that the scenarios for the case study are designed along the central energy transition development visions of chapter two.

The reconstruction of urban structures is probably the most long-term process in the entire transition process. Although the city undergoes a constant change and transformation and redefines itself by this constant change (Böhme 2010, p. 20), the infrastructure is a very stable element, which influences and forms urban transition processes (Siebel 2010, p. 31). This is certainly caused by the tremendous costs of infrastructural measures next to the legal constraints existing ownership-structures impose. This is certainly a barrier for the implementation of measures and adds a lot of uncertainty to the assumed development trends. In general the assumed trends and development paths are hard to verify and to hedge against developments in the superordinate systems.

The research for this chapter has shown that from literature and the analysis of the case study development figures could be defined that allow the application of the scenarios in chapter ten. The necessary adaptations for the case study application included limitation of the scope on the household sector as the largest and most influential sector of the case studies energy system and a limitation of technologies according to local potentials and on-going developments. This means that the case study scenarios are as specific as the communal energy transition visions. The attempt to design scenarios along the visions 'stories' seems to a practical approach to be verified in chapter ten.

Lingering around the best scenario path at any given point in time is probably the most realistic approach to handle energy transition progress. Energy transition scenarios can help to illustrate the effects of relationships and system dependencies as much as they are known and understood and in a generalised way. Harris & Batty (1993) have shown that trade-off procedures and criteria discussions may occur anywhere in urban planning processes. This is true even more for energy transition processes. The idea of

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running a set of sophisticated models and to implement the optimum solution which comes out neglects that not only boundary conditions and external factors change over time but also the appraisal of the results and the priorities change over time. Scenarios as they were outlined in this chapter are decision support tools and illustrate possible future developments and impacts of defined measures. As was shown they do not replace detailed planning. The aim is to create a picture about options and interactions in the future energy system of the community. This should help decision-makers to understand their role and encourage their active participation in setting the course towards most probable favourable developments for their communities.

In the following chapter the scenarios will be applied to the case study of Wolfhagen. Along the three basic scenario 'stories' possible developments for the community of Wolfhagen until the far-future target year 2050 are evaluated. Communal decision-makers as primary target group for the scenario model can follow the outcomes of principle decisions they take on energy transition strategies. The visualisation on maps facilitates the comprehension of spatial consequences.

10 Application of the scenario model

"All theory, dear friend, is grey, but the golden tree of life springs ever green."
Johann Wolfgang von Goethe (1749 – 1832)

§ 10.1 Introduction

Chapter ten combines the research and findings of the previous chapters into practical application in the context of the case study. This is done by the example of four predefined scenarios that represent different development storylines. For the small community of Wolfhagen the scenario model is displayed in the GIS on the basis on the collected default data and local specifications. The central research questions of this chapter are concerned with the question of whether meaningful results may be derived for the energy transition process in the community and to what extent the GIS application may produce useful additional information next to quantitative evaluation of the core indicators. The chapter can be regarded as a summary of the preceding chapters where most of the factual information was gathered and the core assumptions for the scenarios were developed and reasoned. The community of Wolfhagen consists of the central town of Wolfhagen and the villages which administratively belong to the community. As has been described in the case study description in chapter five the town and the villages are very different in size and as well show different preconditions regarding the central energy transition elements, for instance the state of PV-plants, wind energy and biomass potentials. The evaluation of the different scenarios gives an overview on the development of the communal energy system indicators under the set preconditions and assumptions. For the usefulness of the tool in a practical transition process it is important to stress the transparency and flexibility of the framework. Other than the outcomes of an optimisation model the scenarios are models for discussion that allow the visualisation of potential outcomes on a map. The reference to the existing infrastructures, development history and local barriers and limitations can create a vivid picture of the possible effects of the developments. The scenarios assume a rather constant and linear development which does not display dynamic interactions of different parameters yet. This could well be a target for future elaboration and further research and development work. The far future prognosis is therefore bound to the greatest uncertainties. In connection to the spatial effects of enforced solar or biomass development the mere figures gain more distinctiveness. This is important to create an understanding on what for instance an increase in PV-capacity on roof-tops by two or five per cent per year means in practice. The results of the scenarios fulfil the expectation of creating clear messages. In practice the discussion process will follow on assumptions and measures to create the framework for a second or third modelling cycle with adjusted boundary conditions. The model and the GIS offer very transparent access to the parameters and since the modelling architecture is rather simple, the effects modifications can easily be tracked and discussed. The results show some expectable and some surprising results. Since the community of Wolfhagen has already been very active in the past, the base case scenario already produces good outcomes on the short and medium term. In the long term efficiency pays off in the most sustainable way. The extensive exploitation of renewable energies produces some problems for the demand and supply balance in the long term.

§ 10.2 Methodology

The evaluation of the case study scenarios is done in a combination of GIS and spreadsheet modelling. The reason for using rather simple spreadsheet calculation models is the good interoperability with the GIS architecture. This means that results can easily be transferred from one model to the other. For future applications the integration of the scenario analysis and evaluation functionalities within the GIS programme is a very promising task. In the scope of this PhD work no full GIS integration has been done, mainly because of limited programming experience and the focus of the thesis being more on the planning scope of the research questions. A full integration of energy transition scenario modelling into the ArcGIS software nevertheless is on the wish list for future research and development. The evaluation of the scenarios is done for the entire community area and specifically for the local sub-districts which in most cases include a village and its vicinities. To illustrate the effects of specific scenario developments, maps are used to show spatial consequences and effects for the defined reference years between 2010 and the final target year 2050. This is done exemplarily to give an idea of how the GIS system can be used and how it may help in a more profound understanding of spatial transition. Since the local population takes great influence on the implementation of the measures the community is evaluated both as a whole and in the limits of the sub-districts. This allows for a very specific communication of results. For this chapter the scenario results are referred to the entire community only. A specific evaluation for the spatial boundaries of each sub-district is possible but would not enhance the message of this chapter and the outcomes in general. The approach used in this chapter can be useful for all measures with a strong spatial limit, for instance building refurbishments and decentral district heating systems. Since the data is spatially inclusive and comprehensive future evaluation is a matter of the focus, which can easily be changed to the level of the sub-districts. All default data is endowed with reference values that allow the mapping of the data. The scenarios evaluate the developments of central indicators for reference years in the near and far future. The outcomes are based on a linear development of trends. Since there is still no clear understanding and validated research on dynamic interaction of the different development processes the holistic picture has to be derived from the evaluation and interpretation of the indicator sets.

§ 10.3 Non-energy evaluation parameters

At the beginning of a scenario evaluation for communal energy transition projects stands the question of what a good or bad development for the community means in hard figures. This is part of the political process of creating an idea of what should or must be achieved for a sustainable development of the community. The development of the evaluation matrix should be an issue of the communal transition process and be discussed with the central stakeholders and participants. The analysis of the specific local situation and the definition of the evaluation parameters is the first step on the transition path. As has already been elaborated in chapter two, the rating of developments depends to quite some extent on the specific situation of the community. Additionally there are external factors that cannot or can hardly be influenced by measures. These are the external boundary conditions, e.g. demography, economic development, politics, rules and regulations that are not in the central focus of scenario model. They are therefore assumed the same for all scenarios and not further elaborated. The relationship between specific local conditions and the weighting of indicator developments has been described in chapter two as well.
In this thesis the evaluation parameters for the indicators of specific interest are defined according to common environmental targets set by national and international agreements.

Communal development

The evaluation parameters for the communal development indicators population, demography, unemployment and debts are kept constant for all scenarios. The same applies for the evaluation of the specific local aspects which are exemplarily assumed to be the members of the residents' energy association (for participation), the natural reserves under the FFH-Directive (Flora-Fauna-Habitat) and the connection frequencies of public transport. The status-quo situation for the community regarding the communal development was already elaborated in chapter two and is given in Table 10.1. The central ambition is assumed to be the reduction of the negative effects of demographic change for the community. A high shrinking rate of the total population is regarded a negative development while any positive or stable progression is desirable. Wolfhagen has a high employment rate already. Against the background of a declining population a stable or slightly declining number of the local employees would be a good development. Therefore the actual figure of 2010 is taken as reference for a good development. Regarding the communal debts[51] a significant reduction is necessary to reverse the on-going trend towards excessive indebtedness. Any development away from the high communal debts per inhabitant of 1,700 EUR is assumed to be a good course. Any increasing indebtedness is regarded to be negative. For both targets absolute numbers are given to make the figures less abstract.

COMMUNAL DEVELOPMENT				
				
population (per year)	< 0.06 %	0.06 to 0.0 %	0.0 to -0.2 %	> -0.2 %
demography (ADR)	3.1	2.9	1.1	1.0
employees (at place of residence)	4,700	4,600	4,400	4,399
communal debts (per inhabitant)	790	1,400	1,700	1,701

TABLE 10.1 Evaluation parameters for the communal development indicators (own assumptions)

Specific local aspects

To give some examples for specific local indicators three indicators from different development sectors are chosen for the scenario analysis. These indicators are only examples and they were not elaborated thoroughly. They are mainly meant as placeholders for additional indicators and issues which may be considered important aside the core indicator set representing the energy system development. The assumptions for the indicators are given in Table 10.2. To monitor the residents' participation in the energy supply chain the members of the local energy association are monitored. It is assumed that a slight increase in membership would be a good development while a strong decline would not be favourable. A too drastic increase in membership on the other hand would cause investment problems and a declining interest payment to the members. Regarding the natural reserves in the community it is assumed that a rate above the German average of 9 % of the total area would

51 The communal debts include all debts of the communal public household for investment loans without debts of municipal enterprises.

be a good result for the community. Any value below that would be considered unfavourable. To monitor the quality of public transport only the frequency of departures is monitored. This is mainly because the frequency has been the central issue of discussion in the context of public transportation in Wolfhagen. The current frequency lies at 120 minutes for the city bus. This means that any development of creating a more attractive public transport for the city at a higher frequency would be regarded positive.

SPECIFIC LOCAL ASPECTS				
				
members in ESCO assoc. (compared to previous decade)	5 %	0 %	-5 %	-10 %
Natural reserves (FFH) (of total)	15 %	10 %	5 %	< 5.0 %
Public transport (every ... minutes)	30	60	120	180

TABLE 10.2 Evaluation parameters for the indicators of specific local aspects

The development of these indicators is the same for all the considered scenarios. This is mainly to concentrate on the central issues of this thesis and the context of energy transition. There are certainly interesting crosslinks to the energy systems that could be further elaborated. For instance the question of how a shrinking and aging population affects the interest in energy production and participation in the ESCO association. Also the development of communal debts will certainly affect the engagement of the community in innovative projects or the refurbishment of their building stock. On the other hand these effects are to a great extent dependent on political strategies and national policies which are out of the scope of this project. The results of these indicators derive from the population prognosis and own assumptions on the future development. For the scenarios the employment is assumed to remain stable until 2020 and then decline by yearly 0.5 % until 2030. Since there is also a significant loss in total population the number of employees declines as well in the long-term perspective. On the other hand the community has successfully decoupled the employment from the declining population meaning that the number of employees has not declined proportionally but increased over the past decades. It is assumed that the community can keep up this positive strategy in the field of employment and economic development. Regarding the communal debts it is assumed that after a decade of further increase (by 0.5 %) the community succeeds in decreasing their debts moderately by 1 % until 2040 and 1.5 % per year until 2050. In practice the evaluation parameters would be an issue of periodical revision and agreement between political and public stakeholders and the population. Since it is not probable or even useful to stick to constant evaluation parameters for all indicators over very long timespans it is useful to understand the evaluation parameters as the scenario assumptions as an occasion for discussion on targets and measures.

§ 10.4 Limitations of the global evaluation parameters

The CO_2-emissions are a central evaluation parameter in the section of the global evaluation indicators. For this indicator the national targets are taken as evaluation reference since they represent the superior political strategies in the context of climate change prevention. In the context of this project the focus is laid upon the energy consumption connected with household electricity and heat. This is only a subsection of the total energy consumption profile of a community and its inhabitants. The unconsidered fractions affect the overall results to a different degree. While the heating and cooling demand for non-residential building-use in the specific case of the small-sized rural commuter town of Wolfhagen only represents a small fraction of the total and will most probably not alter the results significantly. A significant contribution to the overall CO_2-emissions of the private sector, the households and the community in general is the transportation sector. Transportation has been left out of the considerations in this project, because the case study community does not focus on transportation and mobility issues in the transition project. The measures taken for an improvement in this field of interest do not exceed first steps towards greater acceptance of e-mobility. Therefore the global indicators for mobility would have been a continuous quantity in all scenarios. Regarding the overall evaluation of the CO_2-emissions, the achievements have to be read with the footnote “except transportation”. Roughly the final energy demand and the connected CO_2-emissions from the transportation sector account for one third of the total. Depending on the studies and the question of system boundaries the per capita CO_2-emissions from transportation ranges from 1.56 t to 2.52 t CO_2-equivalent per year (Schächtele & Hertle 2007). Taking the only the lower value without the assumptions for flight traffic emissions, the CO_2-balance for the community of Wolfhagen would change according to Table 10.3.

YEAR	2010	2020	2030	2040	2050
Population (total)	13,828	13,468	12,614	11,994	11,400
CO_2-emissions from transportation [t per a]	21,573	21,010	19,678	18,711	17,784
Emission development incl. transportation (base year 1990)					
Base Case scenario	6.2 %	-20.6 %	-24.8 %	-28.9 %	-33.1 %
Energy efficiency scenario	6.2 %	-27.9 %	-39.7 %	-54.5 %	-68.4 %
Renewable energies scenario	6.4 %	-24.4 %	-31.9 %	-35.1 %	-30.4 %
Smart cities scenario	7.2 %	-24.6 %	-33.5 %	-41.1 %	-48.4 %

TABLE 10.3 Effects of the CO_2-emissions from the transportation sector on the development evaluation

If the transportation emissions are taken into account, the reduction targets are still reached by all scenarios for the year 2020. In the on-going development only the efficiency scenario is able to compensate the transportation sector to a good extent until the year 2030 to achieve the targets. From then on all scenarios miss the targets. This is not surprising and only means that further efforts have to be made in the sector of mobility as well as in the sectors electricity and heat. A greater share of e-mobility could as well contribute to better results for the local energy system, since a greater share of load-shifting can be realised.

§ 10.5 Result of the communal development indicators

The results of the communal development indicators are given in Table 10.4. A summary of the most important single indicators is given in Figure 10.1, Figure 10.2 and Figure 10.3. The trends of the communal development indicators are assumed the same for all scenarios. Therefore they are explained before the scenarios are discussed.

YEAR	2010	2020	2030	2040	2050
Population (total)	13,828	13,468	12,614	11,994	11,400
Population (compared to previous decade)	-4.18 %	-2.60 %	-6.34 %	-4.91 %	-4.95 %
Age structure (total)					
below 6	691	581	515	475	436
6 to 15	1,189	1,247	1,168	1,036	937
16 to 65	8,947	8,312	7,176	6,814	6,285
over 65	3,001	3,326	3,752	3,664	3,747
Age structure (percentage)					
below 6	5.0 %	4.3 %	4.1 %	4.0 %	3.8 %
6 to 15	8.6 %	9.3 %	9.3 %	8.6 %	8.2 %
16 to 65	64.7 %	61.7 %	56.9 %	56.8 %	55.1 %
over 65	21.7 %	24.7 %	29.7 %	30.5 %	32.9 %
Ratio 16 to 65 per 1 over 65	3.0	2.5	1.9	1.9	1.7
Employees (assumptions p.a.)	until	0.0 %	-0.5 %	-1.0 %	-1.0 %
Employees (at place of residence)	4,492	4,689	4,460	4,033	3,648
Employees (compared to previous decade)	5.1 %	4.4 %	-4.9 %	-9.6 %	-9.6 %
Debts (assumptions p.a.)	until	0.0 %	1.0 %	-1.0 %	-1.5 %
Debts (total) [T€]	16,403	20,226	22,342	20,206	17,372
Debts per inhabitant	1,186	1,502	1,771	1,685	1,524

TABLE 10.4 Results for the communal development indicators in all scenarios

From this overview, some central results are given in the following diagrams.

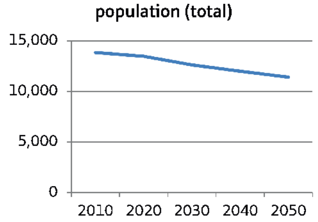

FIGURE 10.1 Population development

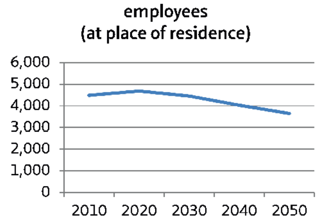

FIGURE 10.2 Development of employees

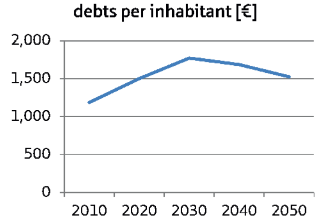

FIGURE 10.3 Development of debts

Regarding the distribution of the different age groups, the community will most probably show similar developments as comparable communities in Germany (Figure 10.4, Figure 10.5, Figure 10.6). There are no on-going activities which could substantially alter the development of over-aging within the population. This means that the share of the 'working population' of 16 to 65 years of age declines over the decades. While the relative share of the young and very young population declines only slightly the share of the population in retirement age over 65 years increases significantly.

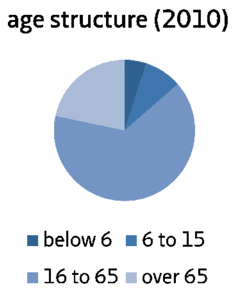

FIGURE 10.4 age structure 2010

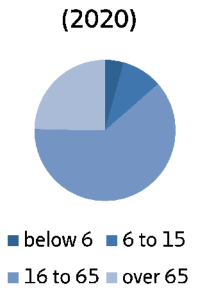

FIGURE 10.5 age structure 2020

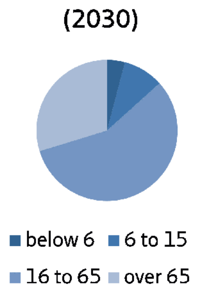

FIGURE 10.6 age structure 2030

The total number of households will reduce in the community over the coming decades. According to the prognosis of the Federal Office for Population Development (BiB) the distribution of household sizes is not strongly affected by the changes in age structures. In communities the size of Wolfhagen the share of single-households is about one third of all households while in larger cities the share is more than fifty percent. The secondary single households only play a minor role in small communities as Wolfhagen. Therefore a slight shift in single and two-person households over the scenario time does not significantly affect the results (Figure 10.7).

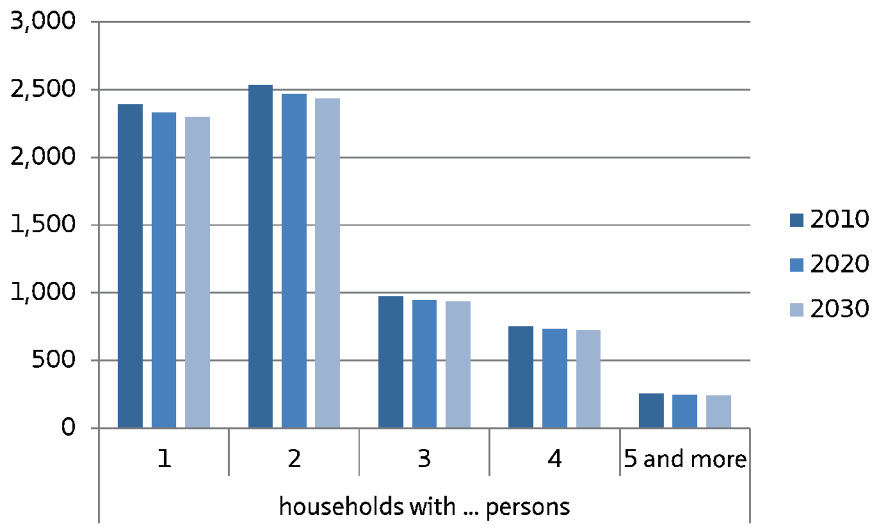

FIGURE 10.7 Development of household structures in the case study

The problems of a shrinking and aging population seem to become visible in the growing building vacancies and the decay of old building structures which are often located in the old village centres. In these unrefurbished historic buildings the problems of demographic change seem to become most apparent. When the few elderly people who often are the last occupants of these problematic properties pass away or move to elderly homes they leave their homes with a problematic aggregation of refurbishment back-log and open inheritance situations. This is often coupled with exaggerated expectations on the real estate value which is a barrier for a quick resale and refurbishment. This in many cases makes the handling of vacancies an important urban development task which has to be thought in the context of new housing developments and restructuring of historic ensembles.

Figure 10.8 shows the documented vacancies in residential buildings in the village of Bründersen for the year 2010 and a possible situation for 2050 with an assumed vacancy rate of 15 % which is assumed by national statistics as a possible development. The actual vacancies in the village cover approximately 4 % of the residential buildings and are mostly historic buildings with a significant refurbishment back-log. On the basis of the building status today a good guess on the future development can be made.

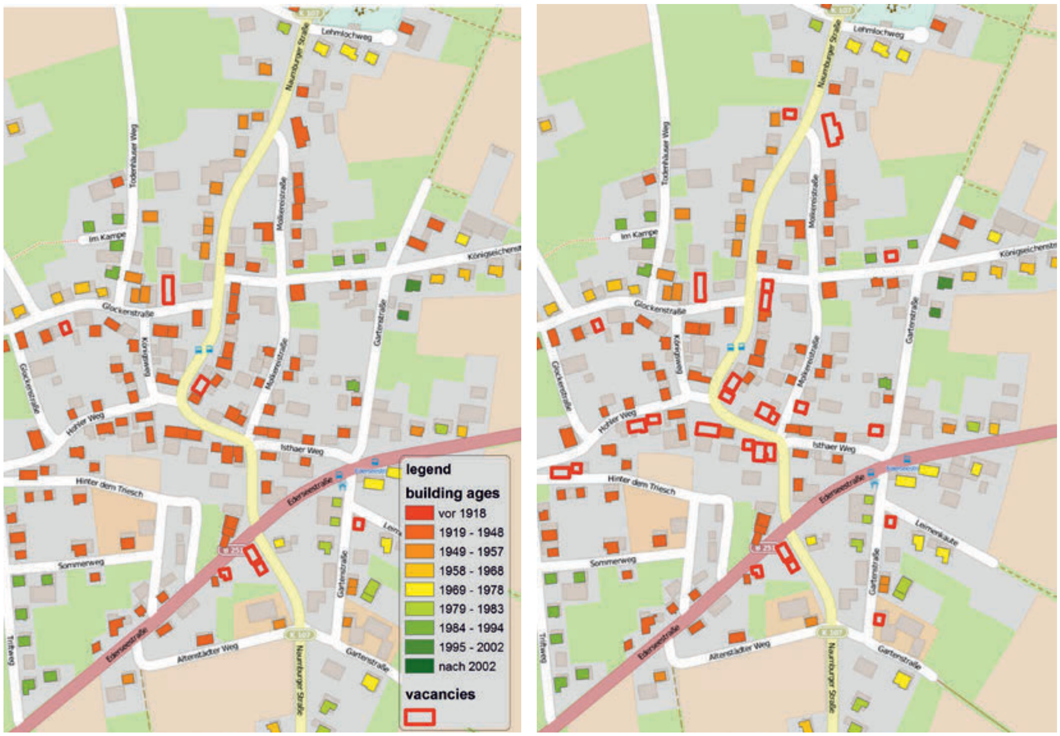

FIGURE 10.8 Documented vacancies in Bründersen 2010 and a possible situation with a vacancy rate of 15 % in 2050

The map shows the need and urgency to address the issue of refurbishments and strategic long-term town and village development to avoid the deconstruction of the villages and towns from the cores, which would mean a visible down-turn of the architectural appearance in general. The displayed vacancy areas only focus on the residential buildings, vacancies and building decay affects the existing agricultural buildings in the village centres as well. In a structural redevelopment process not only residential or heated buildings have to be taken under consideration but as well unused adjoining buildings. They can be the key to substantial restructuring which offers new options for long-term use and sustainable liveable historic town centres.

§ 10.6 Results of the local indicators

The local indicators are meant to cover specific questions of the community which want to be tracked over a certain period of time. To complete the picture of the evaluation matrix three indicators were chosen. The development is assumed to be stable for the base-case scenario. Table 10.5 gives the results.

YEAR	2010	2020	2030	2040	2050
Local indicators					
members in local energy assoc.	0	700	800	900	1,000
development (compared to previous decade)	-	-	14 %	13 %	11 %
natural reserves FFH (total) [ha]	567.7	567.7	567.7	567.7	567.7
FFH areas of total [%]	5.1 %	5.1 %	5.1 %	5.1 %	5.1 %
public transport frequency (minutes)	60	120	120	120	120

TABLE 10.5 Results for the specific local indicators in all scenarios

The development of the specific local indicators is an assumption and serves as an example for the option to include more specific non-energetic aspects into the model. For the community of Wolfhagen the local energy association is an important driver for renewable energy projects. In the past years the association has been very successful in attracting new members. For the future it is assumed that the rate of new memberships will slow down. For the evaluation of the local indicators it is assumed a moderate increase in membership of the local energy association is good. A decline would be negative.

Because of the local anchoring and the mission of the energy association the development of membership is limited. For the natural reserves under the FFH and bird protection regulation the national percentage was set as reference value. According to the National Agency for Nature Conversation 9.3 % of the terrestrial spaces were reported as FFH areas. Reaching the national value would be regarded a good development for the community. The public transport in the community underwent a redevelopment in 2012. From then on four city bus lines replaced the hailed share taxi concept. At the same time the offered transport frequency was reduced from a one-hour to a two-hour frequency. Since this was intensely discussed and criticised any frequency below one hour is regarded unfavourable.

§ 10.7 Results of the base-case scenario

The base-case scenario represent the current trends and the answers the question how the community could develop if no specific further action is taken to accelerate energy transition. For the comparison of the different energy scenario 'stories' only the results of the global environment indicators and the indicators on the local energy system are of interest. The results of the base-case are based on the assumption that refurbishment activity remains at approximately 0.8 % of the residential area per year. After the completion of the wind park the development in the renewable energy sector slows down significantly. Only PV-plants are still added to the system at a low rate.

The evaluation starts with a table which gives all the results of the section as an overview. The most important indicators from the table are given as graphical figures afterwards. These indicators are used for the overall graphic evaluation at the end of each sub-chapter. The section following the graphs tries to explain and interprets the outcomes for the different indicators.

§ 10.7.1 Global environment

The development of the central global environment indicators are mainly determined by the population development and household development for the electricity demand. Building refurbishments and vacancies influence the overall heating energy demand. The CO_2-emissions assigned to the local consumption are highly dependent on the development of the national emission factors. The base year 2010 monitoring data is available from (Icha 2014). The future developments are assumed according to Brischke *et al.* (2012). Here an energy transition strategy on a national scale is assumed. For the local renewable energies the CO_2-emissions are assumed according to IWU (2014) and calculated according to the development in the renewable energies for the different scenarios. The assumed CO_2-emission factors for the national electricity mix and the local production in the scenarios are given in Table 10.6 and Figure 10.9.

CO_2-FACTORS AND DEVELOPMENT [g/kWh]	2010	2020	2030	2040	2050
German national electricity mix	542	320	210	120	50
Local mix base-case scenario	41	26	26	27	27
Local mix energy-efficiency scenario	41	26	26	27	27
Local mix renewable energies scenario	41	29	35	41	47
Local mix smart cities scenario	41	25	26	26	26

TABLE 10.6 CO_2-emission factors used for the local production and the upstream electricity net (after Icha (2014); Brischke *et al.* (2012) and own calculation)

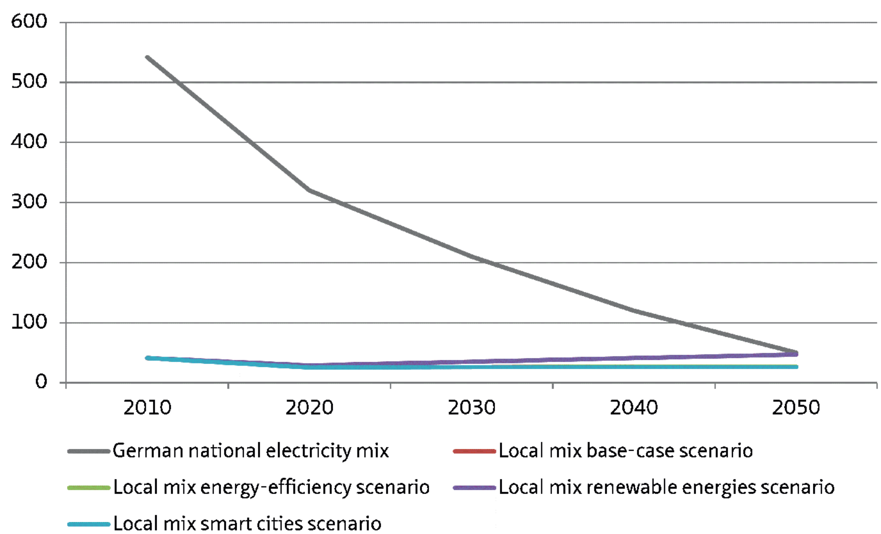

FIGURE 10.9 CO_2-emission factors used for the local production and the upstream electricity net (diagram display of Table 10.6)

For all scenarios it is assumed that surplus electricity can be exported to the national grid and there replaces electricity of the national mix. With the on-going development this may be regarded an optimistic approach since with increasing input from fluctuating renewables in the overall electricity grid local over capacities become more probable and the need for disconnection of decentral renewables becomes more urgent to maintain the grid stable. An increasing threat of grid instability will affect those scenarios most that are based on high fluctuating renewable capacities. The future adaptation of boundary conditions in energy economics for instance taxation, incentives and market-opening is not considered in this project but will certainly become one of the essential parameters for energy transition in a larger context. The increase in the local CO_2-emissions in the renewable energies scenario may seem odd on a first view. It is caused by the dominance of photovoltaic systems in the energy system development. This results in the situation that the CO_2-emission factor for the Wolfhagen energy mix is only slightly below the national mix at the final target year 2050.

Since the base-case scenario describes an extrapolation of the current trends the results regarding both CO_2-emissions and renewable electricity production are already very positive. This is mainly because of the large-scale wind energy plants which are in place since 2014 and the continuous increase of PV-capacity. These are considered on-going trends in the case study since a study without the already realised plants would make no sense. Since the development for large-scale wind energy and biomass is assumed to be completed by 2020 only the PV-installations increase the yearly renewables production on a moderate level.

YEAR	2010	2020	2030	2040	2050
CO_2-emissions (heating, DHW, electricity)					
total [t]	43,614	27,722	26,472	24,941	23,287
per inhabitant [t]	3.2	2.1	2.1	2.1	2.0
developement (compared to 1990)	-28.9 %	-54.8 %	-56.9 %	-59.3 %	-62.0 %
final energy demand					
total [MWh/a]	201,359	191,572	186,952	181,535	176,117
per inhabitant [MWh/a]	14.6	14.2	14.8	15.1	15.4
developmet (compared to 1990)	20.5 %	14.6 %	11.8 %	8.6 %	5.4 %
electricity [MWh/a]	50,002	50,002	50,002	50,002	50,002
heat [MWh/a]	151,356	141,570	136,950	131,532	126,114
renewable energies					
total (electricity) [MWh/a]	29,645	61,397	62,270	63,143	64,016
solar [MWh/a]	17,461	18,073	18,946	19,819	20,692
wind [MWh/a]	6,953	38,094	38,094	38,094	38,094
biomass [MWh/a]	5,230	5,230	5,230	5,230	5,230
share RES electricity [%]	59.3 %	122.8 %	124.5 %	126.3 %	128.0 %
share RES electricity and heat [%]	14.7 %	32.0 %	33.3 %	34.8 %	36.3 %

TABLE 10.7 Results for the global environment indicators in the base-case scenario

Because of the incomprehensibility of the table, the most important results are given additionally as charts diagrams (Figure 10.10, Figure 10.11, Figure 10.12).

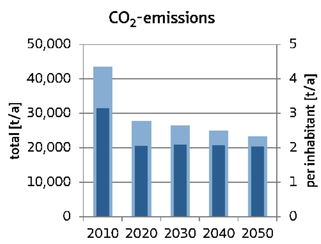

FIGURE 10.10 CO_2 emissions

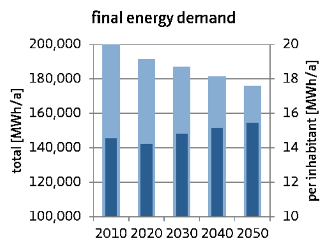

FIGURE 10.11 Final energy demand

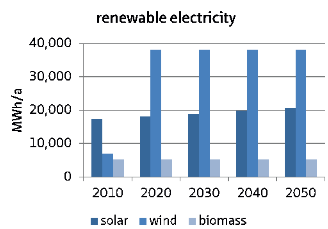

FIGURE 10.12 RES electricity

With a decreasing population and only moderate energy-savings the final energy demand per inhabitants remains almost constant. The large decrease in CO_2-emissions is caused predominately by the development in the upstream or national production pool which is assumed to show significant decreases in emission factors.

For the evaluation of the global environment indicators the European 20-20-20 reduction targets are used as reference in all the scenarios. This means that a good development would show 20 % CO_2-emission reduction and 20 % final energy reduction compared to 1990 until 2020. For the coverage rate of electricity and heating demands from renewable sources the EU-targets strive for 20 % as well. Until 2050 80 % CO_2-emission reduction is the committed target. The targets for the final energy consumption are extrapolated accordingly. In the base-case scenario the targets for the CO_2-emission reduction can be reached for 2020 and 2030. This is because of the contribution of the wind energy plants. Because of the stagnation in renewable exploitation combined with no further efforts in energy efficiency the long-term goals cannot be achieved. Especially the final energy consumption does not fall below the base year value of 1990 throughout the scenario period although there is a decrease in final energy consumption as well.

§ 10.7.2 Local energy system

The indicators on the local energy system shall give an idea on rate of local electricity and heat production and the share of fossil energy systems. In the base-case the local renewables contribute roughly one third of the total final energy demand for electricity and heating of the households. For the local energy system not only the absolute quantity on a yearly basis is an important indicator but also the question of whether the demand can be covered on a smaller time fraction. The extremes of production deficits and over production on a monthly basis can add a more differentiated view on the balancing of the local energy system. For this indicator high deficits and high over productions are not very favourable because they mean a high dependency of upstream net infrastructure and production capacities. Large deficits mostly derive from the large heating energy demands in the winter months. High overproduction is caused by low overall energy demands in the summer months in combination with large solar capacities. An optimal local energy system would give low deficit values and low overproduction as well. The local coverage is only indicative and is the yearly difference between total local demand and total local production. Table 10.8 gives the results for the indicators for the local energy system.

YEAR	2010	2020	2030	2040	2050
demand-supply parity					
local coverage (electr.+ heat) [MWh]	-150,142	-108,257	-101,348	-93,642	-86,035
extreme deficit [%]	-96.1 %	-85.4 %	-84.6 %	-83.8 %	-82.8 %
extreme overproduction [%]	0.0 %	5.5 %	9.6 %	14.2 %	18.8 %
local autonomy					
fossil heating systems [%]	75.0 %	75.0 %	75.0 %	75.0 %	75.0 %
renewable heating systems [%]	25.0 %	25.0 %	25.0 %	25.0 %	25.0 %

TABLE 10.8 Results for the local energy systems indicators in the base-case scenario

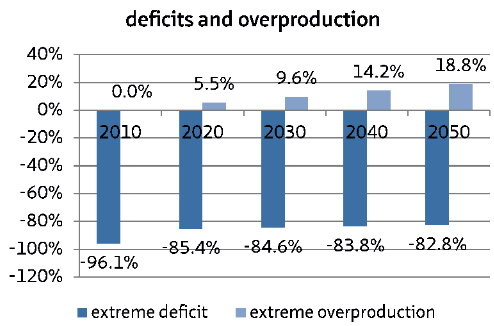

FIGURE 10.13 Monthly extremes of deficits and overproduction

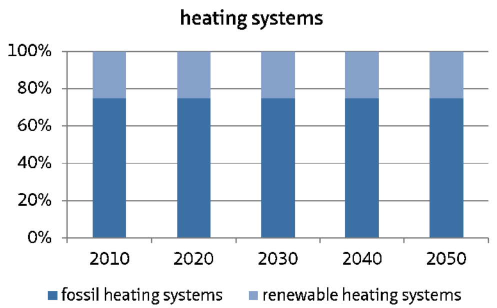

FIGURE 10.14 shares of fossil based and renewable heating systems

The overproduction increases moderately over time in the base case scenario while the deficits decline slightly. This is caused by the moderate increase in PV-installations in the base case scenario which causes increasing overproduction in the summer months. The decrease of the deficits is caused by the moderate energy efficiency increase due to building refurbishments. These affect the total energy demand mostly in the winter months and cause a better balancing with the renewable production.

The heating systems are not altered in the base case scenario. The share of fossil and renewable heating systems therefore remains constant in the base case scenario.

§ 10.7.3 Overall evaluation

The evaluation of the scenarios is done according to the evaluation matrix developed in chapter two. Additionally the developments can be illustrated on the maps to show the local effects of measures and developments. This is only shown exemplarily in this chapter. The full implementation of the scenarios is done in the course of the research project "Wolfhagen 100 %EE" on a web-map service in cooperation with a GIS developer. Since the base-case scenario does not foresee substantial changes in the energy system maps will be used mainly in the other scenarios to illustrate effects. To give an example, Figure 10.15 shows the existing PV-installations in the village of Istha which is the village with the highest density of existing PV-installations in the community.

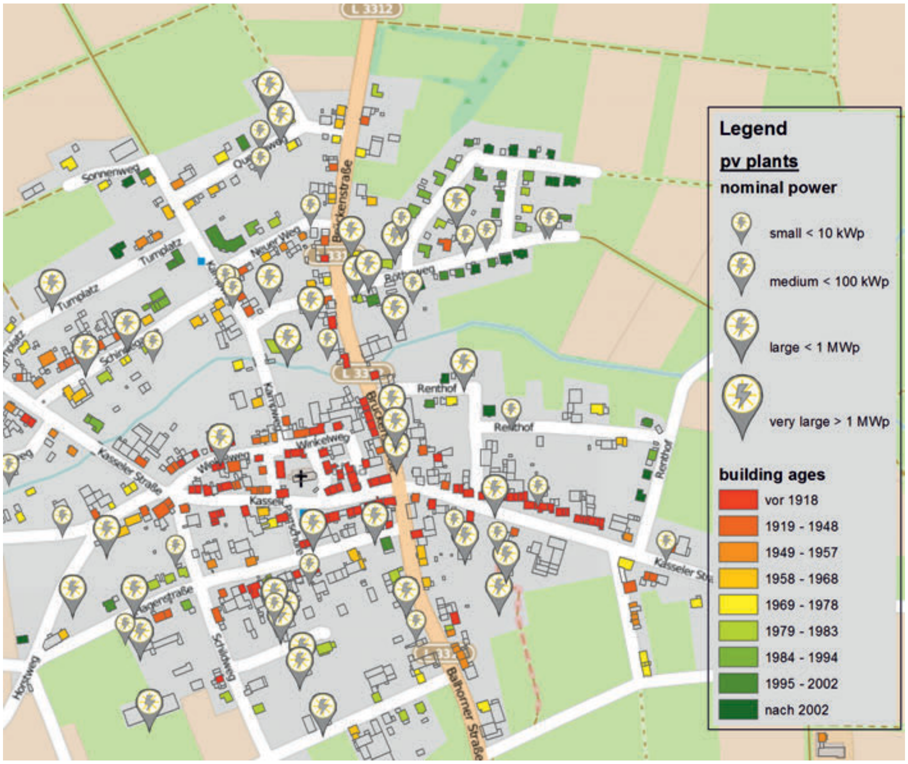

FIGURE 10.15 Existing PV-installations in Istha

If the outcomes for the scenarios are combined with the evaluation parameters and put into the illustration layout from chapter two the development over the scenario timeframe can be visualised in an overview. In this case the evaluation is based on the same development targets and parameters for each decade. In a practical transition process both evaluation criteria and targets would undergo continuous revision to adapt them to on-going developments and priority shifts. Along with the evaluation of the period of interest new directions and specific emphasis on targeted measures would be discussed and determined for the upcoming period.

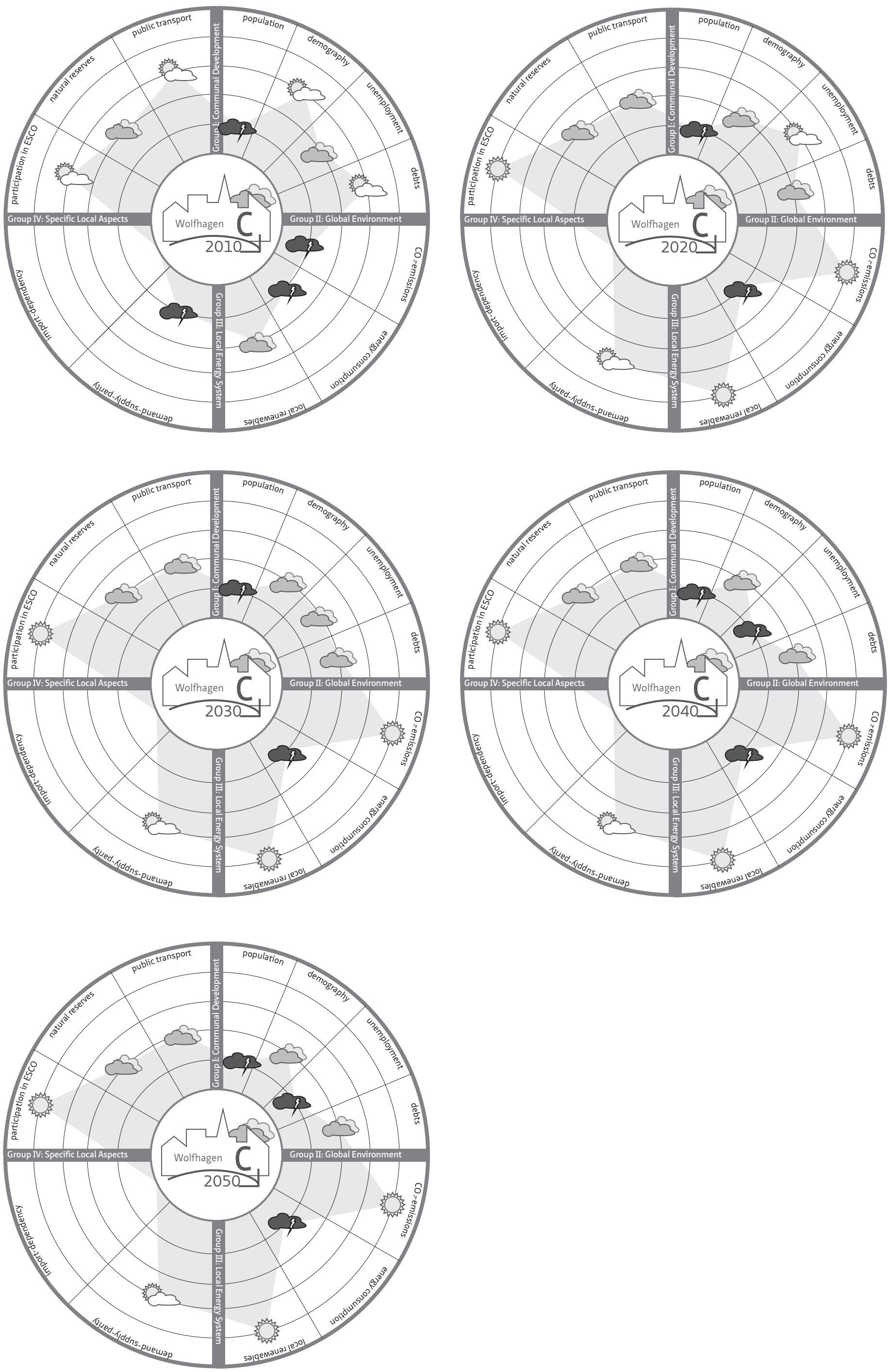

FIGURE 10.16 Indicator overview for the base-case scenario from 2010 to 2050. Until the final target year of 2050 there is hardly any change towards better ‘weather’

Under the given evaluation parameters the community reaches a good rating for CO_2-emissions and local renewables quickly. The electricity production of the new wind energy plants mainly fulfils this goal. In the later years the development cannot keep-up with the progress of requirements for the CO_2-emissions. The rating falls back to only moderately well results. The final energy consumption which is determined mainly by efficiency and energy-savings measures cannot be affected positively in the base-case scenario and remains at unfavourable levels. Since the renewable electricity from wind energy and solar remain the only local renewable energy sources, despite the already existing biomass boilers, there is no positive development regarding the ranking in the local renewables indicator. As a conclusion it can be said that the realised renewable energy plants give the community a boost in the CO_2-emission reduction, which can comply with the targets until 2030, neglecting transportation emissions. None of the other indicators reach favourable results. This means that population decline in combination with building vacancies and reduced household numbers do not automatically lead towards a positive trend in the energy system.

§ 10.8 Results of the energy-efficiency scenario

§ 10.8.1 Introduction

The results of the energy-efficiency scenario show the effects of increased efforts in building refurbishments and electricity savings. With the refurbishment measures the final energy consumption of the building stock is affected positively. For the energy-efficiency scenario it is assumed that efforts in building refurbishment are enforced significantly and the household electricity demand can be reduced by 2 % annually. For the efficiency scenario it is assumed that between 2010 and 2020 the refurbishment rate can be raised to 1.5 % per year. Between 2020 and 2025 2.0 % are assumed and from 2025 until the end of the scenario timeframe a yearly refurbishment rate of 3.0 % is assumed. This is the rate numerous studies have identified as the necessary and desirable rate for retrofitting the German building stock (Habermann-Nieße *et al.* 2012, Bundesregierung 2010, Stryi-Hipp *et al.* 2015, Feser *et al.* 2015). To take the feasibility into account the refurbishment quality has not been assumed to be passive-house standard but represents a low-energy standard applicable to the existing building stock. On a map illustration the effects of an enforced refurbishment activity can be visualised on a district level, in this case by a random selection of building spaces. The replacement rate of 5 % for inefficient heating systems means that every year approximately 170 old heating systems have to be replaced. At this exchange rate all existing constant temperature boilers can be replaced by the year 2020. By the year 2050 there are only condensing boilers in combination with solar thermal panels left. Since there is no energy carrier shift foreseen in this scenario the share of renewable heating systems remains the same. In the energy-efficiency scenario the CO_2-emission reduction proceeds much quicker. The EU-targets of an 80 % reduction for the year 2050 can already be reached between 2030 and 2040. Also the share of 20 % renewables target for heating and electricity is reached by 2020. Figure 10.17 shows a map segment of the village of Istha showing the refurbished buildings in the year 2020 in a random distribution according to the assumptions of the scenario. Figure 10.18 shows the replaced heating systems of the same period. Since the replacement rate of boilers is higher than the refurbishment rate only a fraction of the buildings receive a full refurbishment of the building envelope and the heating system.

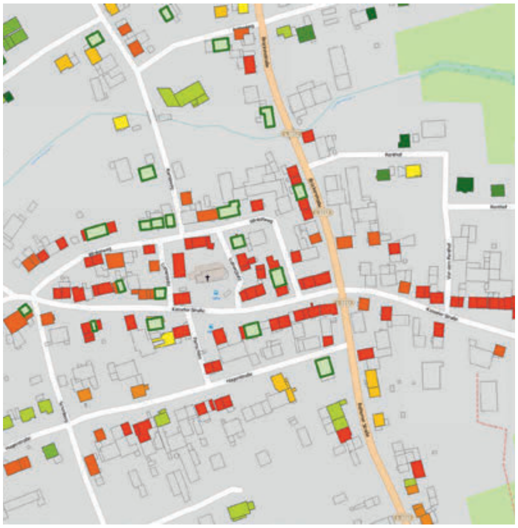

FIGURE 10.17 Buildings refurbished by 2020 in Istha

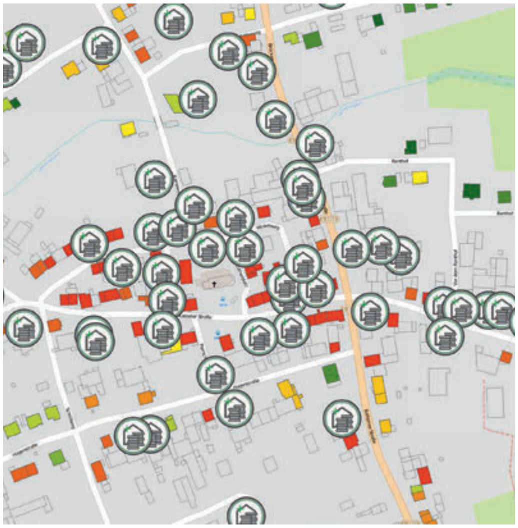

FIGURE 10.18 Boilers replaced by 2020 in Istha

The high refurbishment rates lead to a substantial renewal of the building stock by the final scenario year but demands a continuous and consequent building retrofitting activity. The assumption of a higher replacement rate in the heating systems is probably realistic and leads to a quick drop in CO_2-emissions and final energy demands. On the other hand this leads to the situation that with proceeding refurbishment activity buildings with rather new heating systems undergo refurbishment. This leads to either a drop in boiler life-spans or over-dimensioned heating systems in refurbished buildings. Ideally the refurbishments and the boiler replacements should be adjusted to one another. This is often not the case in practice.

§ 10.8.2 Global environment

The enforced activity in building refurbishment and boiler replacement leads to a quick decrease in the final energy demands for heating and hot water. In combination with the already installed renewable energy plants a very low CO_2-result is achieved for the final target year. The results for the share of local renewables develop positive as well. This results from the decreasing demand for electricity and heat. Even though the development of renewable energy plants does not exceed the assumptions of the base-case, the combination of already achieved renewable energy production and strong energy-savings results in the best result of all scenarios for the global energy indicators. The renewable electricity production in combination with the refurbishments and energy-savings leads to a full renewable supply by the final target year 2050. These results are all based on a yearly balance and the assumption of a one on one trade-off of renewable electricity and heat demand.

YEAR	2010	2020	2030	2040	2050
CO_2-emissions (heating, DHW, electr.)					
total [t]	43,614	23,250	17,326	9,208	1,634
per inhabitant [t]	3.2	1.7	1.4	0.8	0.1
development (compared to 1990)	-28.9 %	-62.1 %	-71.8 %	-85.0 %	-97.3 %
final energy demand					
total [MWh]	201,359	171,636	140,631	97,523	55,583
per inhabitant [MWh]	14.6	12.7	11.1	8.1	4.9
development (compared to 1990)	20.5 %	2.7 %	-15.9 %	-41.7 %	-66.7 %
electricity [MWh]	50,002	43,505	35,681	29,288	24,065
heat [MWh]	151.356	128,131	104,951	68,235	31,518
renewable energies					
total (electricity) [MWh/a]	29,645	61,397	62,270	63,143	64,016
solar [MWh/a]	17,461	18,073	18,946	19,819	20,692
wind [MWh/a]	6,953	38,094	38,094	38,094	38,094
biomass [MWh/a]	5,230	5,230	5,230	5,230	5,230
share RES electricity [%]	59.3 %	141.1 %	174.5 %	215.6 %	266.0 %
share RES electricity and heat [%]	14.7 %	35.8 %	44.3 %	64.7 %	115.2 %

TABLE 10.9 Results for the global environment indicators in the energy-efficiency scenario

The three central development indicators are shown in Figures 10.19, 10.20 and 10.21.

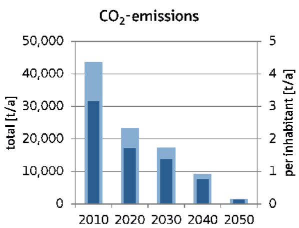

FIGURE 10.19 CO_2 emissions

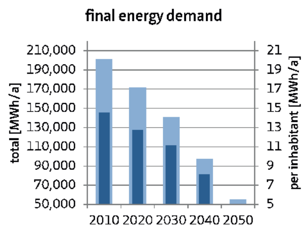

FIGURE 10.20 Final energy demand

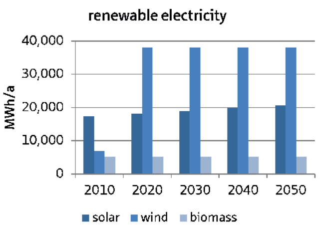

FIGURE 10.21 RES electricity

The CO_2-emisisons and the final energy demand show a quick drop in the energy-efficiency scenario. This is caused by the effects of the refurbishment measures which are increased and speeded-up for this scenario. The renewable electricity production is the same as in the base case scenario, therefore only a moderate increase in PV-production can be observed.

§ 10.8.3 Local energy system

With increasing efficiency the maximum monthly deficits from the heating energy demands in the winter are reduced. This leads to better results for the local parity indicator on a medium term. Since overproduction in the summer months from the large existing PV-capacities gets more impact, the local parity result gets worse in the long-term. Since the scenario does not foresee a change in energy carriers for the heating systems the share of renewable and fossil heating systems is constant. An overview of the results is given in Table 10.10. The central indicators are given as graphs in Figure 10.22 and Figure 10.23.

YEAR	2010	2020	2030	2040	2050
demand-supply parity					
local coverage (electr.+ heat) [MWh]	-150,088	-87,836	-53,133	-8,005	-35,436
extreme deficit [%]	-96.1 %	-83.4 %	-78.2 %	-62.5 %	0.0 %
extreme overproduction [%]	0,0 %	20.6 %	54.5 %	117.3 %	246.2 %
maximum deficit / overproduction [%]	96.1 %	83.4 %	78.2 %	117.3 %	246.2 %
local autonomy					
fossil heating systems [%]	75.0 %	75.0 %	75.0 %	75.0 %	75.0 %
renewable heating systems [%]	25.0 %	25.0 %	25.0 %	25.0 %	25.0 %

TABLE 10.10 Results for the local energy systems indicators in the energy-efficiency scenario

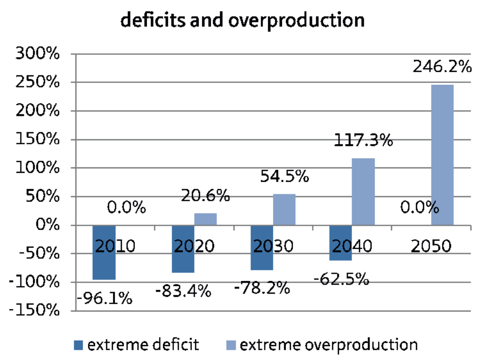

FIGURE 10.22 Monthly extremes of deficits and overproduction

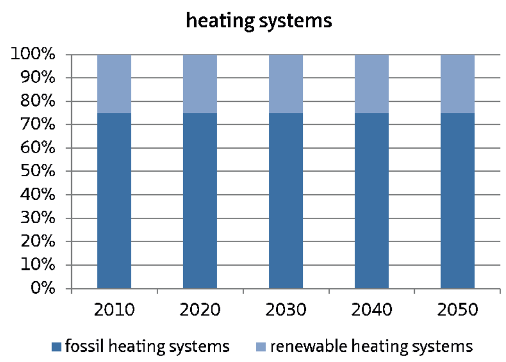

FIGURE 10.23 shares of fossil based and renewable heating systems

The results show the effects of local overproduction of renewable electricity. This overproduction occurs in the summer months. In the efficiency scenario the huge (relative) over-production is caused by the severe reduction on the demand side. By 2050 the entire heating demand can be balanced by renewable production. The limited heating demand in the summer causes the high over-production. The heating systems are not varied and changed in the energy-efficiency scenario, therefore the shares stay constant.

§ 10.8.4 Overall evaluation

The refurbishment activities mostly affect the outcomes for the final energy evaluation. There is a continuous progress towards a good development in this indicator. The results for the renewables and the CO_2-emissions are equivalent to the base-case scenario although the development is much more rapid. The CO_2-emissions per person reached by the year 2050 in the base-case scenario are already reached twenty years earlier in the efficiency scenario. Since the heating and domestic hot water demands dominate the results for the final energy outcome, the efficiency measures have the greatest impact here. With decreasing energy demands the energy system of the community the overproduction in the summer months dominate the outcomes of the parity indicator towards the end of the scenario timespan. In the year 2050 there is more renewable energy produced than is used for electricity and heating. This means that the 100 % renewable goal can be reached without the further excessive exploitation of renewables but as well by a strong focus on energy-saving measures. Assuming that there is no fundamental change in energy carriers, this is of course a balancing and trade-off result. There is basically no change in the import and price dependency for fossil energy carriers except that the quantities are reduced. The evaluation of the core indicators for the reference years is shown in Figure 10.24.

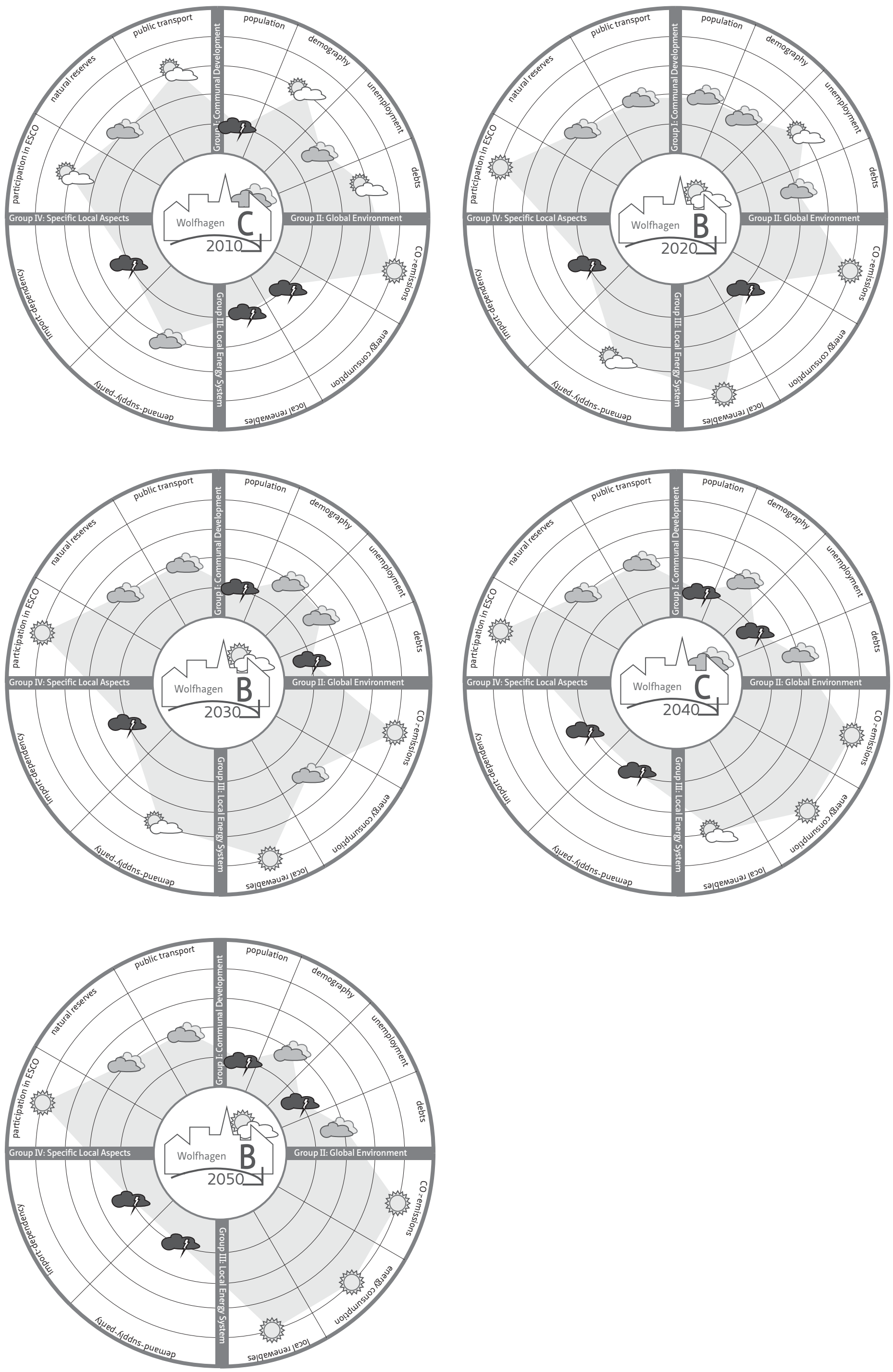

FIGURE 10.24 Indicator overview for the energy-efficiency scenario from 2010 to 2050. ‘Sunny weather’ for the global environment indicators

The positive effects of increased refurbishments and the replacement of inefficient heating systems show a positive long-term development mostly for the global environment indicators. The efficiency strategy is not leading to positive effects on the local matching because by the reduced overall demand a dis-balance is created. Unsurprisingly the improvement and maintenance of fossil fuelled boilers does not lead to a larger share of renewables in the heating sector.

§ 10.9 Results of the renewable energies scenario

§ 10.9.1 Introduction

The renewable energies scenario aims at achieving a local autarchy by exploitation of the available renewable sources. In the case study this means that the largest share has to be contributed from the exploitable solar potentials for electricity and hot water production. The scenario sets its focus on renewable production rather than energy-savings. This means that for the refurbishment rates and the electricity consumption the base-case assumptions are used in the renewable energies scenario. The central question of the scenario is if a 100 % renewable supply for heating and electricity is possible merely on the basis of exploiting the existing renewable resources. To transform the heating sector to renewable energy sources the existing fossil boilers are replaced by heating systems on the basis of renewable energy sources, mainly decentral biomass boilers and heat pumps. Also the solar thermal energy use is enforced. By the end of the scenario period in 2050 all residential buildings are equipped with solar thermal collectors for the domestic hot water production. The share of the solar thermal contribution reduces the final energy demand in the heating sector. Since the wind energy potentials for large-scale turbines are already exploited and the old existing wind energy park has already been repowered the main potentials are left in the solar potentials and in using the local biomass mainly for energy purposes.

§ 10.9.2 Global environment

Because of the large share of renewable electricity from the large-scale wind energy plants the results for the CO_2-emissions are very positive until 2040. This is caused by the additional PV-plants in combination with the existing renewable mix in the community. For the overall CO_2-balance it is assumed that the renewable energy produced in Wolfhagen replaces electricity of the national mix. Because of the development in the national mix the balance benefit reduces over time since the CO_2-emission factors of the national mix get better. The CO_2-emissions connected to the local production are allocated to the renewable electricity from Wolfhagen. Since the community cannot exploit more large-scale wind energy plants but relies mainly on the development of photovoltaic plants and biomass, which have higher CO_2-emission factors, the national CO_2-factors fall below the values for Wolfhagen in the long-term. This leads to increasing CO_2-emissions for the case study community towards 2040. At no time in the scenario the CO_2 emissions for Wolfhagen turn negative, this means that despite the increasing overproduction in the electricity sector the community can never over compensate the total CO_2-emissions from the heating and the electricity sector in a yearly balance. The final energy demand decreases only slightly and even produce higher results than in the base-case scenario. This can be explained by the strategy of energy carrier shifts. Compared to the high-efficiency boilers which are used to replace old boilers in the base-case scenario, the decentral biomass boilers have lower efficiencies and therefore cause higher final energy demands. The solar thermal systems for domestic hot water production cannot compensate this difference in efficiency.

YEAR	2010	2020	2030	2040	2050
CO_2-emissions (heating, DHW, electr.)					
total [t]	43,681	25,405	22,082	21,133	24,907
per inhabitant [t]	3.2	1.9	1.8	1.8	2.2
development (compared to 1990)	-28.8 %	-58.6 %	-64.0 %	-65.6 %	-59.4 %
final energy demand					
total [MWh]	200,992	199,906	203,015	199,252	197,479
per inhabitant [MWh]	14.5	14.8	16.1	16.6	17.3
development (compared to 1990)	20.0 %	19.6 %	21.4 %	19.2 %	18.1 %
electricity [MWh]	50,114	52,131	53,780	55,411	56,413
heat [MWh]	150,878	147,774	149,235	143,841	141,066
renewable energies					
total (electricity) [MWh]	29,645	72,553	96,857	136,139	201,634
solar (electricity) [MWh]	17,461	26,629	46,600	81,550	142,713
wind (electricity) [MWh]	6,953	40,380	44,189	47,999	51,808
biomass (electricity) [MWh]	5,230	5,544	6,067	6,590	7,113
share RES electricity [%]	60.2 %	147.3 %	196.6 %	276.3 %	409.3 %
share RES electricity and heat [%]	14.7 %	36.3 %	47.7 %	68.3 %	102.1 %

TABLE 10.11 Results for the global environment indicators in the renewable energies scenario

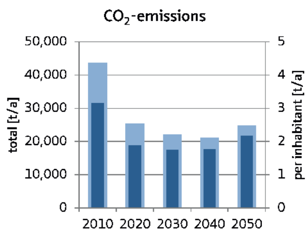

FIGURE 10.25 CO_2 emissions

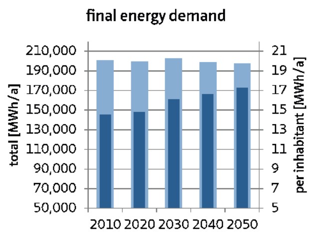

FIGURE 10.26 Final energy demand

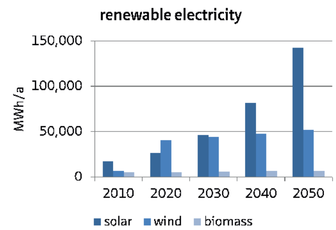

FIGURE 10.27 RES electricity

To reach the 100 % target for the final energy demand for heating and electricity the solar potential has to be fully exploited and the entire biomass potential is used energetically. The installed PV-production in the final target year 2050 is nearly three times the wind energy production. This demands solar installations on all available and suitable roof areas.

§ 10.9.3 Local energy system

The strong focus on the exploitation of solar energy results in large overproduction capacities in the summer months which exceed the deficits in the winter months already in 2030. The shift to renewable heating systems leads to a quick drop in fossil systems. Until 2050 almost all heating systems can be replaced with heating systems based on renewable fuels. Since the approach in the renewable scenario is mostly detached decentral solutions, 52 % of the heating systems in 2050 is based on biomass, 20 % are heat pumps. A significant share of 13 % is equipped with direct electricity heating.

YEAR	2010	2020	2030	2040	2050
demand-supply parity					
local coverage (electr.+ heat) [MWh]	-170,829	-119,437	-87,534	-40,820	32,180
extreme deficit [%]	-96.6 %	-86.0 %	-83.5 %	-80.3 %	-76.1 %
extreme overproduction [%]	0.0 %	25.2 %	96.3 %	219.1 %	434.0 %
maximum deficit / overproduction [%]	96.6 %	86.0 %	96.3 %	219.1 %	434.0 %
local autonomy					
fossil heating systems [%]	74.0 %	54.0 %	34.0 %	14.4 %	6.7 %
renewable heating systems [%]	26.0 %	46.0 %	66.0 %	85.6 %	93.3 %

TABLE 10.12 Results for the local energy systems indicators in the renewable energies scenario

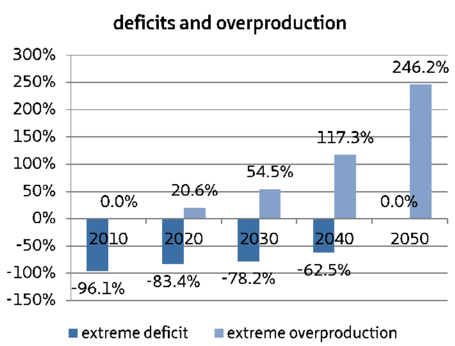

FIGURE 10.28 Monthly extremes of deficits and overproduction

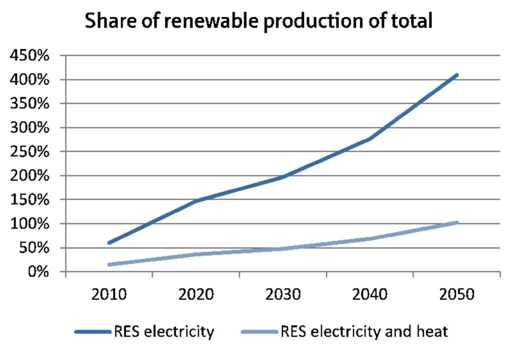

FIGURE 10.29 Shares of RES of total

Taking into account both electricity and heat demands on a yearly balance the community is a net-exporter of energy by the final target year of 2050. This means that the 100 % renewable targets can be achieved by the scenario strategy.

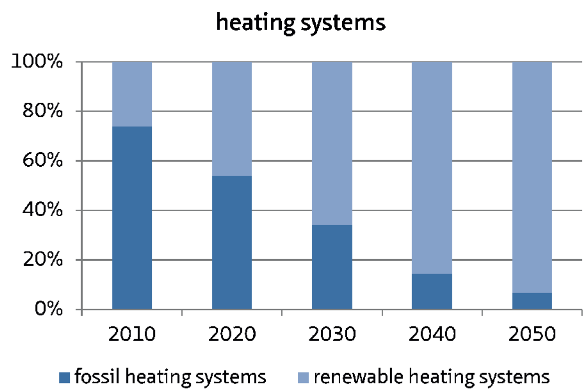

FIGURE 10.30 Shares of fossil based and renewable heating systems

§ 10.9.4 Overall evaluation

It shows that under the chosen boundary conditions the renewable energies scenario does not produce as good results as one would expect. The strategy of exploiting renewable energy sources rather than trying to limit energy consumption does neither result in good long-term results for the global energy indicators nor does it fundamentally decrease the dependencies of the energy system on the superior energy infrastructure. In this case the good results for the import-dependency indicator are somewhat misleading. Since the indicator only describes the share of heating systems based on renewable energies the impacts on other sectors are not represented clearly. The full exploitation of forest biomass for heating energy purposes eliminates the options for any other material use of the available biomass resources. The limitations of extended biomass use become most clear in this scenario. The scenario shows that a full 100 % renewable supply for the community is possible but at high costs. The need to balance the local demands against energy exports demands a superior grid which can absorb and process all the export peaks at any time. The community is 100 % renewable mainly at the cost of the regional and national electricity infrastructure and the binding of local resources for energy consumption. The primary focus on PV-electricity will lead to an unfavourable development in the global environment indicators in the long run. This contradicts the 100 % idea of being the blue-print for a sustainable and environmentally friendly energy system on a small-scale.

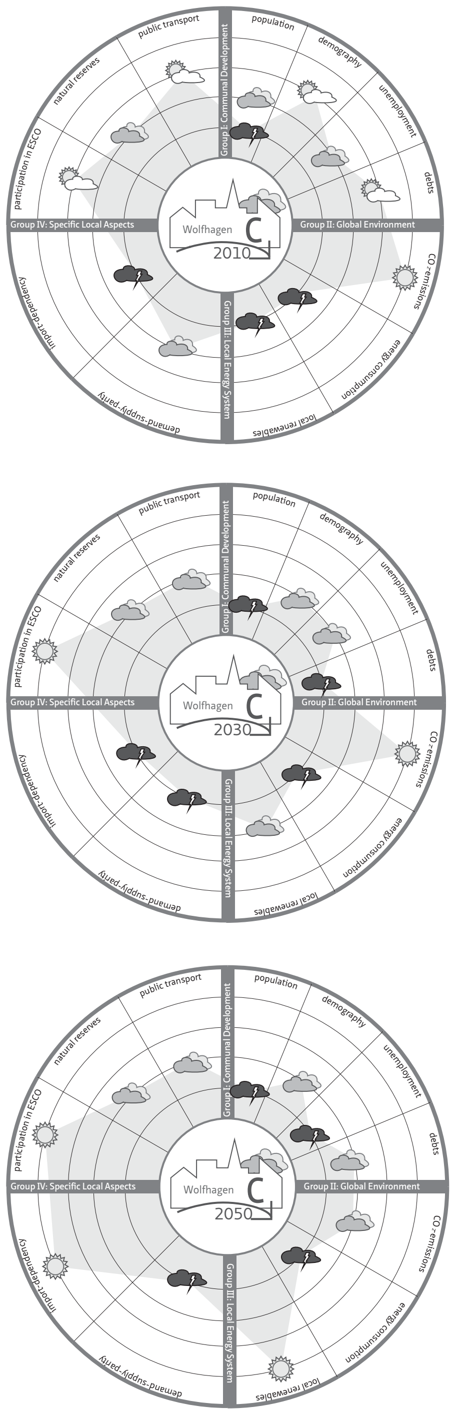

FIGURE 10.31 Indicator overview for the renewable energies scenario from 2010 to 2050. Good results for local production and renewable supply systems

§ 10.10 Results of the smart-city scenario

The smart-city scenario tries a balanced approach of moderate refurbishment and energy-saving activity in combination with a transition of the existing energy systems towards more renewable and cross-linked systems. The guiding principles of the scenario are the idea that local renewable sources are limited, either by their renewal rates as biomass or by available harvest area as solar and wind energy. The scenario follows the idea that for the integration of large amounts of renewable electricity into the energy system a local buffer is needed. This is achieved by a stronger emphasis on electricity based heating systems in the households especially heat pumps and grid-integrated direct boilers for instance for domestic hot water production. The refurbishment rate is kept at 1.5 % annually, the assumptions for the energy quality after refurbishment is the same as in all the scenarios. The lower refurbishment rate is complemented by a yearly exchange rate of 2 % for boilers. This results in a better matching of building refurbishments and heating system exchange. At the same time a change in energy carrier is foreseen for all new heating systems to comply with the renewable targets. This way the fossil based heating systems are phased out almost completely by 2050 as in the renewables scenario. The emphasis for the replacement of heating system is on electric heat pumps which reach a share of 47 %. To reduce the pressure on the local biomass potentials biomass boilers are replaced by heat pumps or district heating as well which results in only 7 % of decentral biomass boilers in 2050. The free biomass potentials are used in CHP-plants for district heating grids. Compared to the renewable energies scenario the biomass potential is exploited only to a degree that conflicts in material utilisation can be avoided. In the scope an extended heating network development the heat potentials of CHP biogas can be integrated into the energy system.

§ 10.10.1 Global environment

The drop in CO_2-emissions for the smart-city scenario is comparable to the renewable energies scenario for the first decades but does not show the reversal of trend towards the last decades of the analysis. The target of an 80 % reduction of CO_2-emissions for the year 2050 is only missed by 2.6 %. Therefore it can be concluded that the overall trend is leading in the correct direction. Basically all indicators in the global environment section show a good long-term trend. Although the 100 % goal cannot be reached by 2050 there is a continuous development towards higher shares of local coverage of the demands.

YEAR	2010	2020	2030	2040	2050
CO_2-emissions (heating, DHW, electr.)					
total [t]	44,227	25,253	21,148	17,399	13,890
per inhabitant [t]	3.2	1.9	1.7	1.5	1.2
development (compared to 1990)	-27.9 %	-58.8 %	-65.5 %	-71.6 %	-77.4 %
final energy demand					
total [MWh]	201,999	183,043	161,475	139,480	118,236
per inhabitant [MWh]	14.6	13.6	12.8	11.6	10.4
development (compared to 1990)	20.8 %	9.5 %	-3.4 %	-16.6 %	-29.3 %
electricity [MWh]	51,121	50,459	48,178	46,769	46,109
heat [MWh]	150,878	132,585	113,297	92,712	72,127
renewable energies					
total (electricity) [MWh/a]	29,645	62,339	64,811	67,329	69,895
solar [MWh/a]	17,461	18,073	18,976	19,925	20,921
wind [MWh/a]	6,953	38,094	38,094	38,094	38,094
biomass [MWh/a]	5,230	5,230	5,230	5,230	5,230
share RES electricity [%]	60.2 %	140.6 %	170.1 %	205.5 %	248.2 %
share RES electricity and heat [%]	14.7 %	34.1 %	40.1 %	48.3 %	59.1 %

TABLE 10.13 Results for the global environment indicators in the smart-city scenario

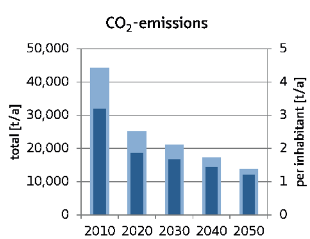

FIGURE 10.32 CO_2 emissions

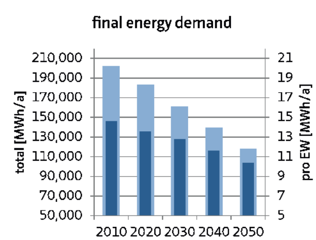

FIGURE 10.33 Final energy demand

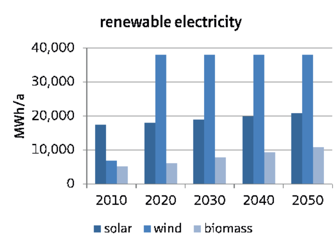

FIGURE 10.34 RES electricity

The scenario shows that despite the additional electricity consumption from heat pumps and direct electric heaters the balance for the renewable electricity remains positive. The assumed energy-savings in the household sector of 1.5 % compensates some of the additional electricity consumption. In combination with building refurbishments the additional energy demand can be limited.

§ 10.10.2 Local energy system

The smart-city scenario aims at good results for the local energy indicators by improving the demand-side integration of both appliances and 'power-to-heat' technologies for the heating sector. The central aim is to create a better balance between the locally produced energy and the energy demand on the basis of a smaller time-scale. With more heat pumps surplus energy mainly from wind energy production in the winter can be used locally in heat pumps. The results regarding the extremes of monthly energy deficits and overproduction are the best results of all scenarios. This means that to some extent the local heating technologies and small-scale DSM can contribute to a more balanced demand and supply side system. With additional technologies such as batteries, as well in e-mobiles, these values could be further improved. The indicator in this project only gives a rough first idea of the effects of a closer heat and electricity interaction.

YEAR	2010	2020	2030	2040	2050
demand-supply parity					
local coverage (electr.+ heat) [MWh]	-150,747	-96,000	-64,367	-39,875	-14,740
extreme deficit [%]	-96.1 %	-83.8 %	-78.9 %	-72.8 %	-61.9 %
extreme overproduction [%]	0.0 %	9.8 %	28.6 %	47.0 %	67.6 %
maximum deficit / overpro-duction [%]	96.1 %	83.8 %	78.9 %	72.8 %	67.6 %
local autonomy					
fossil heating systems [%]	67.9 %	49.5 %	31.2 %	13.2 %	6.2 %
renewable heating systems [%]	32.1 %	50.5 %	68.8 %	86.8 %	93.8 %

TABLE 10.14 Results for the local energy systems indicators in the smart-city scenario

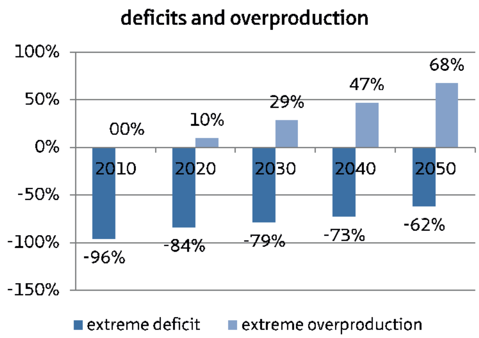

FIGURE 10.35 Monthly extremes of deficits and overproduction

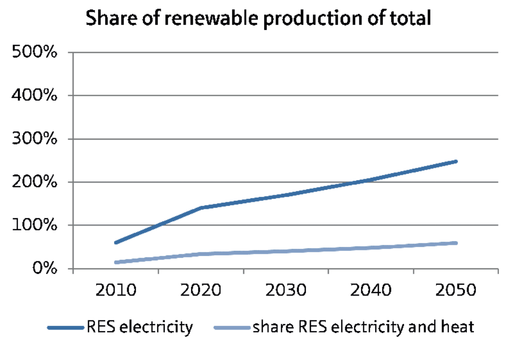

FIGURE 10.36 Shares of RES of total

The scenario does not reach the 100 % goal for heating and electricity from local production. Similar to the renewable energies scenario the fossil based heating systems are faded out by 2050. Additionally the share of inefficient biomass boilers is reduced.

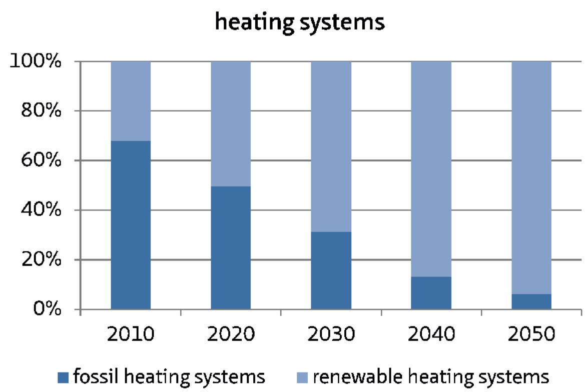

FIGURE 10.37 Shares of fossil based and renewable heating systems

§ 10.10.3 Overall evaluation

The assumptions for the smart-city scenario lead to positive long-term developments until the end of the scenario sequence. All indicators show a slow but continuous development in a positive direction. Only for the local renewable indicator the development is a little slow. As well the final target for the CO_2-emission reduction is missed by a small number. To create optimal results either the refurbishment rate or the local energy production could be slightly increased. Increasing the refurbishment rate would at the same time produce faster progress in the final energy consumption. On the other hand it is very important that all measures in the smart-city scenario are inter-linked to create good results for all indicators within the communities' potentials.

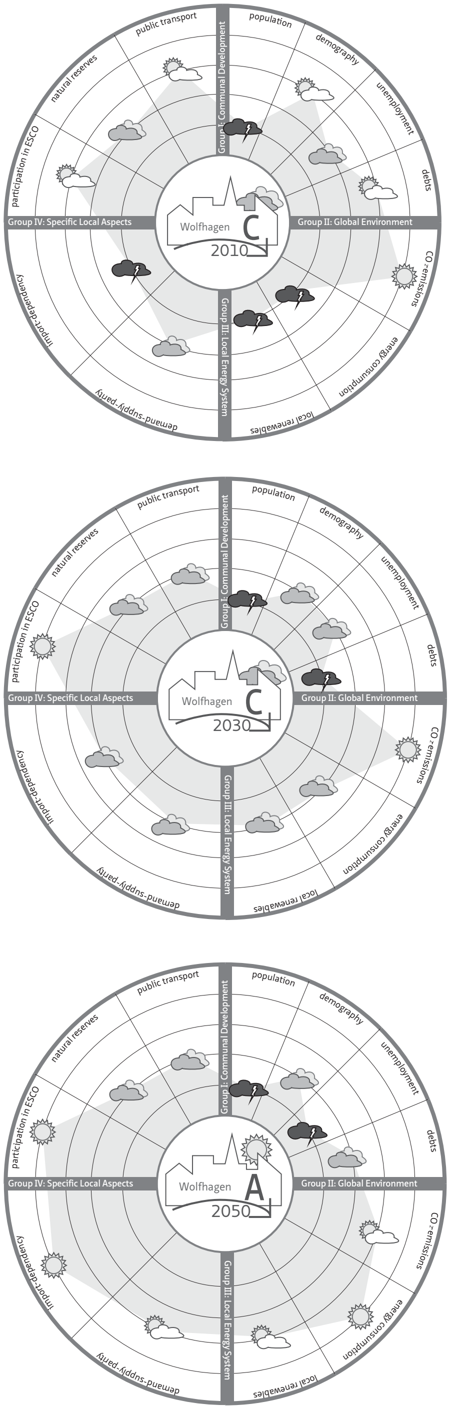

FIGURE 10.38 Indicator overview for the smart-city scenario from 2010 to 2050. Continuous improvements in many indicators lead to long-term sucess

§ 10.11 Conclusions

The scenario evaluation shows some interesting results and shows the principal usability of the approach and the model. The scenario results could be explained from the given boundary conditions and the correlation of the modelled aspects. The scenarios show that the community is indeed already on a very good course. The realisation of the large-scale wind energy park gave the community a boost towards the 100 % goal. The base-case scenario shows that the community already reaches good results for the global energy indicators because of the existing measures. On a medium and long-term these measures are not sufficient though to stay on a good course. The declining population and the reduction of household numbers does not affect the total energy balance significantly, neither do increased vacancies. These may show significant impacts on the urban structures especially in the old town centres and therefore need specific attention in the urban planning process. Especially the long-term developments in some cases produce unexpected results. For instance the rather unfavourable development of CO_2-emissions in the renewable energies scenario was not a predictable result at first glance. Here the effects of the chosen technologies and the effects of superior developments show their impact. As well the huge impact of the assumed efficiency measures was somewhat unexpected. Even though the assumed refurbishment rates do not exceed national recommendations and the efficiency qualities are far from passive-house standard, the efficiency scenario shows the fastest and best results for the global environment indicators. This can be explained by the fact that the demand reduction optimally complements the existing renewable energy strategy and can show its full potential in this combination. The results of the smart-city scenario show the expected and desired trends of a moderate and balanced long-term strategy that leads to a slower but continuous positive development in all the analysed energy system indicators. The long-term trends of the scenarios and the effects of following 'plain' strategies can be visualised well with the model and the developed scheme. The GIS-maps contribute striking spatial reference to abstract figures. This should make it easier to discuss measures and strategies with non-energy experts, stakeholders and the public. The scenario design in the smart-city approach showed the effects of a development path which does not focus on single optimisation aspects but tries to create synergy effects and to realise a long-term trend which does not turn out counterproductive for one or another indicator over time. Therefore the initial research questions connected to the framework application can be answered positively from my point of view. The framework gives good and useful results and offers many options for future extension. Certainly the next and most important aspect to include into the framework is the question of costs and economic effects. The overall investment and operational costs for the measures in the different scenarios will be very different. Efficiency measures especially in the existing building stock are costly while the costs for PV-plants will most probably further decline. This is certainly a shortcoming for the efficiency scenario. A future study could as well look at overall economic effects of the different strategies for the benefit of the community. Basic figures on the economic effects of renewable energy systems are already available (Hirschl *et al*. 2010) and could be implemented. This would certainly make the framework more beneficial for communal stakeholders. The model is transparent and simple enough go this way in the near future and the achieved results of this thesis project are a good basis for this. The realisation of energy systems as sketched in the smart cities scenario still demands some changes in the regulatory boundary conditions and some new technologies mainly in the information and communication technologies. Smart and electricity grid compatible buildings which can contribute services in grid stability are an issue still to come. With flexible electricity prices and more fluctuating supply profiles heat pump and 'power-to-heat' technologies will gain importance. They as well offer the chance to save biomass for the transportation sector and material use.

11 Going beyond 100 % renewables

"Start by doing what's necessary; then do what's possible; and suddenly you are doing the impossible."
Francis of Assisi (1182 - 1226)

§ 11.1 Introduction and methodology

The Danish island of Samsø started its transition process in 1997 when winning a national competition of the Ministry of Energy. The goal of the competition was to present the most convincing ideas to become 100 % self-sufficient on renewable energy. For the competition a master plan was developed which included both the regional potentials and the technological solutions to transform the existing systems. To cut a long story short: Samsø succeeded and during the following ten years ten off-shore and eleven on-shore wind energy plants, three straw heating plants and one solar thermal and wood chip heating plant made the island 100 % self-sufficient on renewable energies. This would be reason enough to learn from the findings and practical experiences the local implementers made on Samsø. Søren Hermansen is now Director of the Energy Academy and one of the central drivers of the past and present projects on renewable energies and sustainable development. Being a native Samsinger he is well acquainted with the local mentalities and ways of thought. This was probably one core success factors to finally achieve the goals and now go beyond. I felt that learning from his first-hand experiences could provide some very valuable findings for the evaluation of my thesis' research work with regard to several central aspects:

- Same vision – similar strategy: Both projects focus on a 100% renewable goal. Both communities started with the electricity sector and attach high importance to the involvement of the local population and stakeholders. I was interested, if the strategies that were chosen for Samsø led to the expected outcomes and if the efforts in participation were successful.
- Samsø is ahead: Energy transition projects in communities are long-term processes. Samsø started about ten years ahead of Wolfhagen. From the experiences on Samsø I hoped to learn something about possible future developments in Wolfhagen and how to avoid setbacks.
- Similarities and differences: For a comparison with the German case study spoke that the island of Samsø is very rural with scattered small-scale villages all over the island.

By coincidence the island's size is exactly as big as the communal area of Wolfhagen (112 km²) but houses only 3,800 permanent residents. I wanted to know how structural differences affect outcomes for the two communities and whether they are critical regarding the final targets.

– Discuss the details: Meeting an expert as Søren Hermansen offers the chance to leave the surface of typical 'best practice'-case study descriptions that you can find everywhere on the internet. I was eager to discuss some detailed problems I had encountered in the case study of Wolfhagen with Mr. Hermansen, for instance the problem of building refurbishments, data availability and motivation of the local public, and hear his view and approaches.

The interview questions were structured so that they would allow a rather informal talk, going from the more general to the more detailed questions and a final résumé. I sent the questions to Søren Hermansen in advance and asked him for an interview.

In December 2012 I had the chance to meet him at the EnergiAkademi in Ballen on Samsø (Figure 11.1 and Figure 11.2). What started as an ugly stormy winter passage on a ferry turned out to become a wonderful inspiring and fun interview which is given below in a slightly shortened version. I tried to preserve some of the spirit and commitment Søren Hermansen showed during our talk by keeping the 'talking-language' as an intentional deviation to the scientific standards of the remaining thesis. I will try to follow-up on the findings in the conclusions.

FIGURE 11.1 Island map of Samsø, Denmark

FIGURE 11.2 The Energy Academy is located in a rural setting

§ 11.2 The status of the project

Mr. Hermansen, the energy island of Samsø is published worldwide as success-story for the step towards energy autonomy and a world based on renewable energies. From your point of view, where does the project stand? What are you working on at the moment?

We are working on a version 2.0 or on the development 'after-renewable energy'. There are a lot of things to do still and this is already in the focus area people are working on at the moment. We don't have to do so much here because the carpenters, the trade people, the municipality, the planning people they are planning according to the success and the state of development we have seen from 1998 when we started until today. So this is in progress. But we need to direct the route every now and then and adjust it according to what new laws, what new regulations and new policies say. There is always something to do in that area but we don't need the strong attention now because the project is up and running. People know what we are talking about, when we approach them, when we have public meetings and other things. So we have said here at the Energy Academy that the next phase will be to eliminate fossil fuels completely, to take them out of the system. This is difficult because this means to take them out of the transportation sector. And being an island we have ferries, we have a lot of transportation of goods on trucks for agricultural products. And these thousands of tons of potatoes and onions and cabbage and processed canned fruits and vegetables are leaving the island every year on trucks and ferries. So it is a big task to say that we will have this on green fuel by 2030 which is the target today.

§ 11.3 Energy potentials

The community of Wolfhagen is exactly the same size as the island of Samsø, it is also a rural community with agriculture but has about three times as many inhabitants. Does the energy system of Samsø have the potential to supply more people with renewable energy or what would the maximum number of inhabitants of Samsø be to maintain your ambitious energy goals?

You could say that we have divided the energy supply in three categories: We have space heating as one of them, which is solemnly based on biomass and energy efficiency. The target was to cut down 20 % of the 1998 consumption of energy per square metre in the houses. And I think we are getting closer to that area. And on the other hand we had to convert all the oil and electricity to biomass. Today the perspective and national opinion has changed a little bit because now we are using more electricity to feed the heat pumps. And many houses that are outside the village structures, farm houses and houses in a stand-alone situation, they have heat pumps. The next phase is electricity and we have an extra production of almost 80 million kilowatt-hours of the off-shore wind turbines, which are all exported today to the mainland. And this belongs to Samsø because it is also passing through our energy structure. This we could use for the transportation or the ferry. We have now ten electric cars in the municipality, in municipal home service, where nurses and people who are social workers, they drive these little Citroen C0 and they service all the people here. And we have some private citizens like the secretary of the house has an electric car. I drive an electric car every day, so it is growing a little bit. So this is the changing of the future development.

So you would say that there is additional potential for supplying, or virtually supplying more people? So you would not say that the good conditions with a lot of space that you have here in Samsø per inhabitant is the precondition for achieving these goals?

Well, you can say that per citizen, the area is big. We have a big footprint or a big area of land per citizen. But I think that we can expand, also including tourism. In the tourist office they say that we have 300,000 overnights, which is one tourist staying one night. And all their energy consumption is also included in our energy survey. And process energy and all the other things as well. So it's not just our 4,000 people on Samsø. It is all activity on Samsø included. So it's quite a lot higher. And then you could say that there is more potential for electricity production. I think we could have more electricity from wind turbines also from solar panels. And I think we can produce more biomass. I think we should look at ourselves as producers of primary products, like food. And I think in the future we will also be net energy exporters to feed Copenhagen and Arhus, all the main capitals, who can't produce anything. So this will be one of the possibilities of activity in the rural area. Not only for ourselves but also for export, so we make some income to make a living here.

§ 11.4 Involving the public

When you started the project, people were sceptical about the technology and the achievability of the targets. How did you identify and convince the opinion leaders to support the project? Would you say that Danish people are keener to experiment than other Europeans?

No, I don't think so. I think they are just as conservative as any other rural area citizens. I think the traditional thinking of the rural area is kind of conservative. Not politically, but socially. For social conservatives changes are probably not good. So let's wait and see and hesitate a little bit. So things that come from Copenhagen or from capitals or consultants and experts might not be good because we have heard it all before and it didn't serve us good in the past. So of course the "what's in it for me?" aspect and the public ownership of ideas is a process more than a statement. The process is where you start to interact with your local community in a way where you don't act as an expert and a consultant. We have this idea: "Are you willing to meet and talk about the future of this island and this community?" And talk about: "Where are you in 2030? And how do you expect to make a living, to serve your family, to have a job?" and all these personal things. We don't talk about energy from the beginning. We talk about the prosperity of the community here. Which is interesting because then you dig out all the worries and the concerns of people. I'm not an engineer, so we can call the engineers when we are ready with the plan and say: now we have a plan, do some calculations, come up with a master-plan. But if we don't do it in that order, then you lose a lot of people. Then it is about an intruder from the outside. I think it is completely the same in Germany, in the small villages and towns and areas because it is the whole soul of these local communities. This is the way they think everywhere. I've seen it in Japan, in America, everywhere it's the same thing. But I think in Germany you have the same possibilities, because you have the feed-in tariff, you have the legal structure. So we can actually compare each other in Denmark and Germany quite easily.

We respect the representations of the stakeholders, so when we try to make a project, where we need farmers involved, we contact the farmers' organisation, where they have an elected chairman of this farmers' association and we invite him. We invite the mayor of the city; we invite whoever is elected from their members to represent for the first meeting. And then we introduce a brief summary of what we want to do, and ask them: "what do you think about this? Can you go home and ask your members about their opinion about this project? Because before we make any decisions we need your opinion." They say: 'alright', they feel very important. They are now part of the process and we invite them to bring up the discussion in their own context. If you don't bring in people from different interest groups in this discussion in a very premature or very early stage then you start an opposition. We fear the unknown more than we are interested in the possibilities. It is a very fragile process in the beginning, where you have to respect and understand the social connections in the local community. And I don't think you can write a book about this, or a manual on how to do it, but you have to feel your way through it and understand the questions. You have to take up fears and go to the meetings, have a cup of coffee, sit down and listen to the talk of the town. Learn something from these processes. Then you can stand up as the energy consultant or the energy office or the energy agency and say: "We have this idea. I am aware of this and that." And people will say: "Alright, someone has been listening to what we have been saying! And that's good. I feel comfortable now and we can go to the next phase of the development." I think this is the most important part of the process to identify and map the whole situation in a social way. You can always call the engineers. That's the easy part. The structure of the project you can do in parallel, but you should not publish it before you have levelled out all these different interest groups and put them on a map.

§ 11.5 Success factors

You have basically answered already my next question: I was interested in your opinion on the most crucial project success factors. And it seems like you have already answered it: Develop the technology parallel but first make sure you have the support and the backing and the good feeling among the people?

That is right. If you are a consultant you are on a limited budget. The budget can be very good and very attractive but it's a limited period. You have to be successful within this period. If you are a politician you are elected for four years and you have to be successful within this period. So everybody is really stressed about being somebody or showing some success within this very short time-span but that is too short for energy planning. Structural energy planning is a long story. It's ten years or more than that. We have to get around the problem of short-minded thinking, because this is where politics is today. We must try to get this issue out of the stressed and surficial planning and get it into the holistic and long-term planning. And include the social aspects as well. I think this is where the whole key is for a successful development.

§ 11.6 The issue of climate change

If you talk about the long-term perspective, there is this issue of climate protection and CO_2-reduction, CO_2-emission and our responsibility here. Would you say that also these more ethical or more moral aspects have attracted and convinced people to take part in the project?

Well, I would say no. The climate issue and the whole environmental issue have to be reduced to almost nothing. You can always bring it up, if somebody asks. But it's a city problem. This is because city people have a bad consciousness about living in a dump. I mean a big city is a big problem. And of course you need to do something for the rainforest in South America and save the whales and be part of Greenpeace and all these other things. And I like Greenpeace a lot because I like warriors. It is fun and

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fine and they make a point, which is good. But I mean Greenpeace has nothing to do here on Samsø and probably not in your town in Germany. So let's leave that for the city people. Because they need something to care about and there is nothing to care about in the city because it is just one big competition about being in the limelight. But here it is about the social aspects of life. And you could say the positive side-effect is a reduction of CO_2 emission and an improved climate. But you have to keep it sorted out like that. This is what is important; this is about good life in the community and of the individual. That you have a good school for your kids; that you can bring them up in a nice and clean environment, that you have a good beach and nature, that you have the forest nearby and you can bicycle around and have a nice time. So who cares about the climate? And you can't do much about that, because if you focus solemnly on this climate issue and the CO_2 reduction targets then people feel alienated in a way: "well, we are not causing the big problems! There are people who are commuting fifty to one hundred kilometres every day on a highway to go to the city to work. They cause the problem. We don't." This is may not be true because we live in old houses and we have a big consumption per square metre. But the problem is, that here it is not on the agenda. If I start talking about climate changes, people say: "Well…?" And they don't really get it because we have blue skies and nice sea around us. So I don't think you should focus too much on this. If you can do it towards the nature organisations, who hate wind turbines, you can say: "That's part of the game. If you want to do something about the climate, we need to eliminate the fossil fuel consumption and produce some energy from wind turbines. So, sorry guys! But this is part of the solution, come up with something better." But these nature people drive along with their big four-wheel drive green cars with their green clothes because they love birds. So I say to them: "Let's start with yourself. What's your personal contribution?" Get them on board in a more direct way. Saying to them: "That's fine. You tell us what you don't want. But let us see how you are going to make a solution." And I see sometimes the farmers and they go clapping their hands.

§ 11.7 Monitoring and communication

Talking about the hard facts: How do you monitor the development of the energy system? How important is the communication of the measured results for maintaining a good motivation to improve further?

We have a quite advanced website, where we have a weekly newsletter in Danish that will come out with all the new findings, if we had a meeting with some interest for the locals. That's one thing. We try to be updated with it. Then we participate in many of the local meetings. So we are trying to have it on different levels, say the organisational

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structure, the direct information to the stakeholders and then a practical assistance platform. And then on the external base we have a direct connection to the ministry for the climate, they like us very much, because we are doing very well. We have a ten years evaluation report. And we update the figures every second year in a full scale all included study of the impact of the big areas that we cover here. So it's very detailed realistic status on the development. And we have done this since 1998.

Do you have access to the electricity consumption of all the houses from the utilities?

Yes, it's a little tricky to get it, because they say: "Ah, it's very complicated, it will use a lot of hours and we have to pay our way through it." But we have come to the agreement that they will deliver every year the consumption. So they have to level it up on road numbers. They deliver the yearly consumption. For oil, we need to ask five different suppliers of oil, nobody of them will give us their data, because it is a market competitive information and we could abuse that and give it to some of the other ones. So until now we have succeeded in having the detailed information on how much oil we did import. And the ferry company, they know exactly how much they buy per year.

Also quite difficult is the transportation sector, to assume a certain amount of kilometres per year?

Yes, but we don't do that. We estimate how much oil was imported to Samsø, oil and gas. So if people fuel on the mainland, we don't account for that.

So you are drawing the boundary line around Samsø?

Yes, of course that's also kind of a statistic, because we also calculate in the consumption of the tourists, who bring their car. Because if you run out of gas, you put on some gas here on Samsø before you go back to Germany, then you would be adding to the consumption of Samsø.

Ok, I will try to avoid that; I will try to make it to the ferry!

Then you break the statistic. But as you can see, we try not to be too detailed about that. Because otherwise you can become so complicated that it is not valuable anyway.

§ 11.8 Efficiency vs. renewable energies

In the news' headlines there is always a strong emphasis on the renewable energy production, both for the electricity and the heat and transportation sectors. Would you say that if we use the available renewable potentials, energy-saving and efficiency becomes less important?

I think not, but you could have a point there because it's easier for us to convince people they should invest in new things. They love that. But to go back and look at their own behaviour and their own houses, is more complicated. They may have just redecorated their house and painted the walls. Nobody wants to change something. It has been like this always and it should be like this always. Where you could say energy conservation is more boring. It is not as sexy as investments like a new solar panel on the roof because then the neighbour can see how alternative you are and how good you are doing. This is something about social behaviour. I think it is not because we don't pay it that much attention from here, but it's because it is not as catchy. But on the other hand, I think we have been quite successful in having a different approach to this, because we educate the carpenters and the plumbers in energy conservation and say to them: "This is your business! So if you can go out and convince the citizens, the house owners, this is a really good investment. Then there is work for you. You can sell more insulation on the roofs. You can sell new windows or new heating systems in the houses and make them more efficient." Even for the electricians, because they can put up smart-home solutions, so you can have a computer to switch on the light from your computer or your iPhone. And actually Samsø is the place where you have the most smart house solutions per citizen anywhere in Denmark. So it works. At some state it was also that Samsø had the most solar panels per inhabitant. So I think it works for people to understand the 'what's in it for me'-element. It's not just a short-sighted one, it is also about education and know-how because if you have a higher level of education and know-how the decision-making is easier, because you know what you are talking about. If you don't know about it and you just hear about it, then it is easier to understand that you can put a solar panel on my roof and get a tax reduction on my tax bill and get a feed-in tariff from the government. That's easy; very short-sighted. I can make this, I can add two plus two and it is this. But it is more difficult to understand that putting in hundred millimetres of extra insulation will pay back itself within five years. It is ok, but what does it mean, I will have to take off my entire roof...

So you are taking the approach that this will kind of filter into society and normal behaviour via the carpenters via the craftsmen who will just propose that more often, more on a standard basis to their customers, so it becomes just a normal thing, when you do something about your house.

Yes, it is about good house-keeping. Where, when I say it it's about attitude. It will be more about the bad consciousness that will drive you or an attitude, whereas good house-keeping is more like: 'This is what we do here!' So the blacksmith says, so the carpenter says, he agrees with me that we should do something about this. In other words, we try to educate our co-citizens in being the ambassadors of the good behaviour. Because if I say it, it has a certain sound in people's ears, it sounds like: "Now he is there again! He wants us to invest a lot of money."

§ 11.9 Matching supply and demand

The energy balance of Samsø is working on a trade-off basis, meaning that you sell surplus electricity to the mainland, which pays-off energy imports. What potentials do you see in a better matching of supply and demand side, for instance by extended demand side management via heat-pumps and storage systems? Do you see any potential there or is it contradicting the benefit aspect of the system?

Right now it is contradicting the system. It is not helping this process. So if I exchange my present energy system with kilowatt-hours from the off-shore wind-turbines, I am not helped by the tax system. For example having an electric boiler in the district heating system, so we could lower the import or the buying of straw from the farmers, because we can buy relatively cheap power in the night-time, when the production is high and the consumption is low. This would make sense. We could use more kilowatt-hours, instead of just exporting them at a low rate, but then the tax guys will come and say: "Hello, if you exchange one fuel with another fuel, then we have to level out the tax." That is typical Danish, because we have a green policy, but the tax guys, they don't care about green or black. They just see, where we have the biggest revenue of the kilowatt-hours is where we have the fossil fuel included. But if you change from fossil fuel or even from CO_2-neutral fuel to completely green energy, then you have to pay the difference in taxes. You have this permission now, you want to change the system, you cannot, you have to follow the old regulation before you change this. This is actually a barrier in many places in Denmark. We have a lot of companies who have some process energy, because they use hot water or they have a lot of external energy, the cool-off energy because they use it for processes. They have a nearby village which is on natural gas. The company could supply the whole village with district heating from their energy loss. But no, it is not profitable, because then you have to pay tax. So they just cool it out in the air and the village keeps on buying natural gas. This is ridiculous. And everybody knows this is ridiculous, but who will make the decision that the government can stop having this tax income? Not until this whole gas system has been paid off and you are out of the contract obligations and all these other things. Because then it would make sense for us to change here also. Of course it would be more interesting to use our electrons here than to export them at a very low price. If you could exchange the kilowatt-hours here with some cheap home-produced kilowatt-hours instead of imported expensive kilowatt-hours, that would make perfect sense. And you should do that to a high up level as possible. But not at all circumstances. If it doesn't make sense, then there is still a sense in exporting excess because it generates an income that will feed the next process. So if people invest their money instead of putting it in the bank or using it for consumption it is better that they buy a share in a wind turbine. And then they get a profit of seven or eight percent and this money they can re-invest in their systems which is our argument also: "Let's produce more, make some money and use this as a kind of home-banking system, where we can generate our own income to invest in the next phase of this.

§ 11.10 Impacts on local employment

Next to the residential investment project in wind power, are there other effects or new businesses or services connected to the transition project?

I think you could say that we have created 30 new jobs here on Samsø. But that was in the traditional businesses, so we didn't create any really new businesses. But on the other hand, we are here with twelve staff members at the energy academy. When we started the project, we were one, which was me. We have five to six thousand visitors per year. So they also stay in hotels and hostels. So they create activity outside the tourist season. We have bigger groups. I think tomorrow we have Japanese that will be here tomorrow. And regular every week we have visitors, next week we Chinese tv will be here on Tuesday. CCTV which is the biggest Chinese tv channel. So this is all creating the attention of many different players, who will come here, work here, use this as an example. I am an associated professor at Aalborg University. Aalborg has close relations with the Delft University and Copenhagen business school and also Fraunhofer. So you could say that it is not direct, it's more or less indirect. So it is that spin-off effect that is not directly evaluated in figures and numbers but you can see that there is this effect of things happening here. There are people that move over here and create their own job on Samsø. The municipality has just hired a person who is working with energy in the municipality. They didn't have a person like this before. This is because we help them make an energy strategy plan for the municipality and now to introduce the energy strategy plan or to make it operational, they need someone to take care of that. So I think the whole activity is interesting seeing it from many different perspectives. But it's not so simple to say that it has this certain effect. But it has kind of a positive spin-off of the whole attention to it.

§ 11.11 Shift of paradigm

Would you say that the project has led to a paradigm shift and a change in mentality for the local residents and maybe even the Danish in general, because you have proved that energy transition is possible? Are people more conscious about their energy consumption now?

Well yes and no. I think that of course you can say that we have seen a paradigm shift. When we started the project, most people said: "It sounds very attractive and very interesting but this can probably not happen here, because we are a small community, we have limited resources and blablah.." You know all these traditional thinking that we know that this is a good thing to do but we don't have the funding, we're poor. And then most of the younger people are not here. The average age is high. So you could also say that all the wild young people who want to change the world, they are not here. They are in Copenhagen at the universities. And people who have small children are not very active in politics or other things because they have their hands full and a lot of things on their minds. And they have to keep the mortgages down. But today, If you asked people the same questions as in 1998 and you asked them again today they would probably say: "Yes, we could do that. It's easy. It's just the thing we do here. It's our politics and this is based on the citizens' involvement what we do here." And this is the paradigm shift, that people overcame their fear of the future and also their fear of change. Because they couldn't foresee what would be the effect of this. I think they thought we were going to change their whole lifestyle here completely. Everything will be green and we will be driving around in electric cars and we will be very sophisticated. And we are not sophisticated. So it's also an attack on their conservatism seen from a historical perspective. Changes take time. And we are so slow on changes here, but the world around us is changing. I mean, just look at the mobile phone now it is a computer, a few years ago it was a big battery with a telephone on top and you had to carry it like fifteen kilo on battery. People don't think about that. They think about what happens up here. So yes, I think we have seen a paradigm shift in thinking here. We can call people and you will have one hundred people in the audience here, all the chairs will be used because people want to know about the changes and the future plans. When people were more afraid before, they wanted to know what they should avoid, where to say no, so nothing will be expected from them without their acceptance. So now they want to be part of the process from the beginning and know what is happening here. And I think that is a positive approach.

Now, when you look into the future, you have achieved a lot. Stating that you can really say: we are 100 % renewable, we are 100 % CO_2-neutral if you want to propose that that way. What spirit or what mind-set can you build upon to go further? Do you have to come up with a new project like we build a new plant or we build more new wind *turbines or is there something that you can kind of progress on towards the future, that you can say now we have this system established and on this path we can proceed.*

I think there will be a natural development of the programme in the future. We don't have to search so much for new ideas because you could say that the houses that we made a survey on ten years ago or twelve years ago already now can be refurbished again. And we can find new energy-savings. So there are a lot of low hanging fruits still to be picked. Another thing is the use of biomass, we need to talk about this and maybe not use so much biomass. We need to bring down the consumption and keep some of the biomass in the soil, so we can keep a better condition for the soil structure. And for this we are looking at biogas. In Germany you have some very efficient and well-working biogas plants on farms, but the problem is that you use food like maize and others as start products for the digestion of the biogas plants because you have a relatively high feed-in tariff for biogas. So this makes the financial balance, which it doesn't in Denmark. Well, we are hoping that the next level of biogas politics here will help the biogas plants using waste and not the difficult waste, not industrial waste, but bio-waste that can be composted and organic waste from processing of food and other sources, which is what we want to do here and there is a lot of places where you can do that in Denmark. And then use that and then we can produce transport energy as natural gas instead of LNG we can use methane upgraded to LNG standards and qualities and stuff. That is possible. We will do that, but right now the financial structure is not there yet. It is too expensive.

§ 11.12 Lessons learned and recommendations

If you could give the decision-makers in Wolfhagen some good advice for their energy transition project, what would that be?

You need to educate and include the local people in the process. It actually starts from the school system and all the way up to the business and citizens' level. Say to them: "We need to implement this green plan everywhere in all layers of society and in all branches of society, so it's kind of a vertical and horizontal introduction of the project and make somebody who is an expert in communication help us. Because communication is not something anybody can do. I mean everybody can talk, but there's a difference between just talking to communicating an idea. And it can be many things, it can be big festivals where you have bands and parties and things to information and capacity building meetings where you actually inform people on different levels. It can be study groups; it can be citizens' activist groups and many different things. Support this, put it in the local budget, have some money you can apply for, if you have a good idea you can have a little seed money to get started for that. I think that is really important, that you have this approach that you actually announce that you want to talk about it. But it is not just talking, not just the coffee, but it's also the practical things we need to stitch this together. So the patchwork will be consisting of many different activists. We don't have to be friends to be in this but you have to know about what is happening over here and over there and then stitch it together as a community.

And then you could say that the consensus about this is also kind of a paradigm shift, but it is still based on a traditional thinking. Saying that if I am a local citizen in your town here and I'm in a low income area, I'll probably have this idea: I can't do much here, but let me know, what I can do. I need to know that. If I know what I can do I can better accept that some of the big business guys they can do much more, they will make a profit out of it, but that's the name of the game, that's how it is. A community consists of people who are profit-oriented and some who are workers and have monthly salary and they go to the pub and they drink some beers and they spend everything and then there is another month, another payment. And then there are the guys who are calculating how they can make a profit. And everybody knows that this is the patchwork of a community. And let both parties be at their level. It is not a community you can't just swing the magic stick and change that.

Mr. Hermansen, thank you very much for your time and this inspiring talk.

FIGURE 11.3 Wind power, first generation

FIGURE 11.4 At the Energy Academy

§ 11.13 Conclusions

What central findings can be derived from an interview in the scope of a PhD thesis? My central aim was to gain some first-hand insight into a project of comparable targets and further in progress. I was eager to hear about experiences and discuss some detail problems we have encountered in Wolfhagen. The interview with Søren Hermansen fulfilled these expectations fully. Regarding the technical outcomes of the transition processes in both communities the results show good success. Wind energy in combination with other measures in energy efficiency and renewable heating has the potential to lead to 100% renewable energy balances. Samsø has achieved this goal for the electricity and heating sector and Wolfhagen is on a good path with 100% renewable electricity supply as an intermediate goal. This is only possible with the support and commitment of local government, stakeholders and inhabitants. Mr. Hermansen made it very clear that energy transition is a bottom-up process when it comes to implementation. The success of the Wolfhagener energy cooperative supports the hypothesis that there has to be 'something in it' for the local residents to convince them. Moral aspects of climate change responsibilities do not play a major role for local action.

The island of Samsø is in the process of defining 'What's next?'-path to follow-up the success story started in 1997. After reaching a significant goal it seems to become more difficult to define new targets. The projects in Samsø are tending to become more diverse, less focussed on the one 'target-number'. Keeping-up attention and commitment is already a problem the energy community in Wolfhagen encounters after reaching the 100% renewable goal in the electricity sector. Follow-up projects tend to be more complicated with less catchy slogans. In both communities the issue of energy efficiency refurbishments demands continuous and persistent efforts. Turning our building stock towards efficient heating systems based on renewable energies appears the Sisyphus task here and there. The first essential milestone in convincing people to work on their buildings is to reach them. A high level of trust in the authorities is necessary to make people listen to what the experts have to say and to fill the assemblies. This means that people have to be asked about their worries and expectations and to start discussion far away from the 'energy-issue' if necessary.

Both Samsø and Wolfhagen represent rather conservative communities in a rural setting. The advantage for long-term transition processes is rootedness and local identification of the inhabitants who mostly show a great commitment for their home. It is therefore beneficial to talk about future possibilities and developments of which energy is one aspect. Mr. Hermansen was very clear about his view that the engineering is only the second step of any successful energy transition process. First the spirits and hearts of the local actors have to be won. For each one of them the personal benefit has to be clear to enable them to participate.

The technical implementation of smart energy solutions, for instance the load-shifting between the fluctuating renewable electricity production and the heating or transportation sector, still needs better legal boundary conditions in both countries. This includes taxation rules which contradict the use of local surplus electricity or the grid-tariffs which unnecessarily raise the costs for electricity-shifting between the sectors. For the case study of Wolfhagen a clear 'ban' for fossil energy carriers in heating as in Denmark would be helpful to increase the incentives for local small-scale heat grids based on renewable CHP or at least semi-central heating based on renewable residues as the straw heating plants on Samsø.

Data availability is problem here and there. Despite this fact that a 'correct' energy model of an entire community might both be illusionary and unnecessary. Regarding the communicative aspect of energy models and scenarios within a transition project, there is still potential that the Energy Academy does not make use of so far.

Søren Hermansen stated a couple of time the importance of bringing university cooperation and student's projects to the island. These creative groups bring in the necessary innovative ideas to continue with the project beyond 100 % renewables. It seems that finding a catchy guiding vision for Samsø 2.0 will not become as easy as following the renewable energies idea. "What's next?" is certainly a core question for the team of Søren Hermansen at the Energy Academy for the coming years. This will be the most important task for the project group in Wolfhagen towards the end of the funding period as well. To remain front runners in energy transition and sustainability the upcoming projects are even more ambitious and more complex in implementation. After having shown the possibilities of renewable energy production, the 'fossil free' energy system will demand even more involvement and personal contributions from the Samsingers and the Wolfhageners.

12 Conclusions, Discussion and Recommendations

"It is good to have an end to journey toward, but it is the journey that matters in the end."
Ursula K Le Guin

§ 12.1 Summary and methodology

This final chapter concludes the research work of this thesis. The framework and background of the research project were covered in chapter one and chapter two. The review of tools and methods was addressed in chapter three. Research results on available data, the development of the modelling framework and the scenario building was the main issue in chapters four to nine. The application of the model to the case study and the final evaluation was the central aim of chapter ten. Chapter eleven started the summary section with an interview with Søren Hermansen from the Energy Academy of Samsø, Denmark. Finally, this concluding chapter gives an overview on the thesis' findings by summarising the results. To each part of the thesis primary and secondary research questions were stated in chapter one. This concluding chapter phrases the answers and ends with a general reflection on the research and an outlook on possible future developments and research needs.

§ 12.2 Main additions to science

The problem statement for this thesis addresses the difficulties of bridging the gap between scientific findings in the energy research field and practical implementation especially in small- and medium-sized communities. Here the implementation of state-of-the-art technologies often lags decades behind the status in scientific discussion on innovative urban energy solutions. This is not a problem limited to small communities but describes the missing link between theory and practice in general. The thesis is aimed at making a contribution to a better understanding of communal energy systems for local decision-makers and other laymen from the scientific side. From the opposite direction the thesis is aimed at transporting the barriers and obstacles of implementation into the scientific discussion. The main additions to science of this thesis are located at the crosslink of theoretical research and practical implementation in the energy transition planning process and vice versa. Since this research thesis originates from my background in the architectural and urban planning field this seemed a worthwhile approach for me. In my understanding research is no value of its own but needs to be measured by its contribution to problem solving. In this case the threats of climate change and the upcoming social, economic and structural upheavals have been the motivation of this project on a very general level. On a practical level my heart beats for the people taking responsibility for the development of their community, most of them on honorary basis in countless initiatives and communal parliaments. It's impressive what they can achieve. Better understanding arises from the analysis of technical systems and their functioning and the understanding of the communal environment where the systems are finally implemented. The central contributions may read as follows.

§ 12.2.1 Making the findings of energy transition research accessible for small- and medium-sized communities

The first two chapters of the thesis covered the specific boundary conditions that can be found in small- and medium-sized communities. Their role in the overall energy transition process has so far been widely neglected by science. Only single aspects mostly deriving from large renewable potentials have been the focus of research on the more rural and small communities. In the scientific discussion this perception leaves the impression of an urban hinterland whose central purpose is to supply the renewable resources the metropolises are unable to produce themselves. This neither does justice to the large share of high-potential residents living in these communities nor to the tremendous potentials the smaller scale and manageable size of these communities offers for the implementation of real front-runners in holistic energy transition. One of these front-runners is the case study community described in chapter five. This thesis addresses small- and medium-sized communities from a holistic perspective. This is to acknowledge the potentials they have in all fields of energy transition. The contribution to the scientific discussion is to give the small players a forum in the science arena and some more self-esteem about their potentials and strategies. To do so, the appropriate tools and framework were established in chapters six, seven and eight. The data for the scenario model was developed in chapter nine. These adapted strategies help to define targets and to anchor the strategies in the planning process. The applicability is tested in chapter ten.

§ 12.2.2 Increased knowledge on the applicability of GIS-models for energy transition in small-scale communities

Chapter four focussed on the functionalities of a GIS-model to contribute to the specific questions of energy systems transition. The GIS architecture in principle offers the necessary functionalities to support the data evaluation to create energy transition scenarios. These specific questions have not yet been implemented in a commercial ready-to-use application. The data compilation in chapters six, seven and eight showed that in principle relevant default data is available to fill GIS-based scenario models. This data framework can be applied to start discussion and planning of a transition project. The GIS architecture allows an easy access and a good communication basis for planning and visualisation. Since small- and medium-sized communities are familiar with the use of GIS applications from urban planning and accounting the implementation barriers are kept as low as possible. The configurations of data and scenarios allow a quick start and specifications during the process. The use of scenario modelling and GIS-applications are not common tools in small- and medium-sized communities. This thesis contributes to the future design of customised solutions integrating the possibilities of modern data analysis and communication tools for the sake of energy transition.

§ 12.2.3 Increased knowledge on practicability of exergy-thinking approaches in energy transition

A guiding principle of energy transition strategies in this research work is the 'Trias Energetica' leading to 'exergy-thinking' in the optimisation of energy systems. The contribution of this thesis to the scientific discussion in the exergy field can be regarded the attempt to avoid exergy analysis and modelling as far as possible and to see how far mere 'exergy-thinking' as planning principle can reach. The findings of this attempt were discussed in chapters two and nine and applied in chapter ten. This thesis' approach to exergy is to some extent contrary to the on-going exergy research in the context of communities, for instance in the IEA Annex64 project 'LowEx Communities – Optimised Performance of Energy Supply Systems with Exergy Principles' where the detailed exergy analysis and modelling is of central interest. To the discussion of this international scientific community this thesis will contribute and continue the polar disputes of implementers and analysts. It is very important to take up this discussion on the practical applicability of exergy tools and evaluation procedures. After more than ten years of intense research on exergy as a new indicator for the performance of energy systems the discussion needs to reflect the chances of bringing exergy thinking into practice.

§ 12.3 Research questions

For the research of this thesis four primary research questions were stated in chapter one. Each of these primary research questions represented one step towards the application of the scenario model of energy systems in small- and medium-sized communities. Each primary research question was subdivided into several secondary research questions which represent the central findings of this research work.

§ 12.3.1 How can communities anchor and monitor long-term energy transition visions in their communal development plans?

This primary research question was the leading research question of the first section on the urban planning framework and the application environment of the model to be developed. The question derived from the experience that communities often have problems with defining their urban development targets for long-term strategies. If targets and goals are defined the transition of the goals into implementation plans and measures often is the next barrier. This is especially the case for long-term developments in energy transition. Since communities depend on the support of their local stakeholders and residents communication is a very important success factor. These central observations from numerous implementation projects formed background of the first research question. This first research question was subdivided into two sub-research questions.

A What role do small- and medium-sized communities play in achieving overall transition goals?

This research question was covered in chapter two. The focus of this thesis was mainly on the small- and medium-sized communities and their stakeholders as primary target group for the scenario model. The central hypothesis was that energy transition on a national scale needs the engagement of small- and medium-sized communities. Because of the decentralised urban structures in Germany and almost all European countries with the large majority of inhabitants living outside the metropolises we must find solutions for the specific needs of small- and medium-sized communities. To answer the research question the central urban planning frameworks were analysed with regard to energy transition processes and the targeted community size.

B What energy visions support communal decision-makers in defining their transition goals?

This research question was covered in chapter two. The hypothesis behind this research question was that communities need strong target visions and clear communication to successfully follow long-term goals in energy transition. For the monitoring and communication meaningful indicators need to be chosen for a community specific communication strategy. To answer this research question popular maxims on communal energy transition were evaluated according their applicability and pros and cons for long-term urban transition strategies. From the common approaches a new transition approach based on 'exergy-thinking' was developed. For the monitoring and communication an indicator framework was developed which allows a specific definition of targets for the community in combination with a subset of comparable meta-indicators on energy system development.

Summary of the findings

The research questions and results have been discussed in chapter one and chapter two of this thesis. A summary of the central findings is given in Table 12.1.

PRIMARY RESEARCH QUESTION	SECONDARY RESEARCH QUESTION	RESULTS SECONDARY RESEARCH QUESTION	RESULTS PRIMARY RESEARCH QUESTION
How can communities anchor and monitor long-term energy transition visions in their communal development plans?	A. What role do small- and medium-sized communities play in achieving overall transition goals?	Large share of total population and public bodies with planning authority. Great impact and potentials for national transition success.	Definition of striking development vision. Definition of reachable sub-goals. Anchor implementation measures in urban development plans and strategies for long-term commitment.
	B. What energy visions support communal decision-makers in de-fining their transition goals?	Energy visions based on exergy-thinking offer flexibility of efficiency and renewable production aspects. Specific set of indicators necessary for communication.	

TABLE 12.1 Summary results primary and secondary research questions section one.

§ 12.3.2 What tools and models are available for urban energy system analysis?

Chapter three was dedicated to basic literature review on existing tools and models. In order to get an overview on the existing approaches the theory of modelling in the field of energy system scenarios was reviewed. The concept of analysing future developments by creating different development scenarios already has a long tradition in the scientific field of future studies. In the literature some summary papers and conceptual analyses can be found. These publications often date back quite some years already, for instance by Grubb *et al.* (1993), Hourcade *et al.* (1996) or Beeck (1999). In the more recent publications the focus is shifting more towards the implementation and case study application of tools. Here often single energy system aspects are the central focus of the developments. The research questions in chapter three were the starting point for the further development of the scenario model in the later chapters. It must be stated that the development of different tools and models in this field has taken a dynamic development over the past years. The evaluation is therefore incomplete and does not cover all developments in the field.

C What tools are available and to what extent are they applicable in the context of small- and medium-sized communities and their planning authorities?

The results of the literature review were given in chapter three. There are several modelling approaches which have been published in the context of energy systems and scenario building. At the time of the review stakeholders in small- and medium-sized communities do not use customised tools for the planning and implementation of energy transition processes. The most standardised and familiar procedure to integrate energy issues into urban strategic planning is the INSEK[52] with the integration of energy issues as described in chapter one (see as well Blesl *et al.* 2012). In the understanding of this thesis the INSEK is more a procedural guideline than a tool. It was therefore not covered in this context. The literature review was meant to get an insight into the methods and tools available and used in the strategic planning of small- and medium-sized communities. It can be stated that they are neither widespread nor commonly used.

52 INSEK = „Integriertes Stadtentwicklungskonzept" (integrated urban development concept)

D What are promising developments and simplifications for the communities in focus?

To facilitate the access to strategic scenario modelling for the communities in focus the literature review concentrated on aspects which could be easily adapted and simplified to contribute to a new and improved approach. It was shown that the very sophisticated scientific models cannot be applied without a great deal of simplification and reorientation towards the target group of communal decision-makers rather than scientists. Especially the question of how the additional questions and tasks could be linked to existing tools in the urban planning departments was of interest. The need for good communication and process steering functionalities are central issues as well.

Summary of the findings

The research questions and results have been discussed in chapter three by the means of a literature study on available and commonly tools and approaches. A summary of the central findings is given in Table 12.2.

PRIMARY RESEARCH QUESTION	SECONDARY RESEARCH QUESTION	RESULTS SECONDARY RESEARCH QUESTION	RESULTS PRIMARY RESEARCH QUESTION
What tools and models are available for urban energy system analysis?	C. What tools are available and to what extent are they applicable in the context of small- and medium-sized communities and their planning authorities?	Tools follow logic of research questions and can be structured according to basic characteristics. Mostly scientific origin without commercial applications for communities.	Broad variety of scientific analysis tools, mostly on spreadsheet basis. Simplified models can be integrated in GIS for better visualisation.
	D. What are promising developments and simplifications for the communities in focus?	Approach of scenario modelling offers flexibility and data framework for purposes of small- and medium-sized communities. Geographic reference adds visualisation and spatial information.	

TABLE 12.2 Summary results primary and secondary research questions section two

§ 12.3.3 How can tools and models be adapted to the specific demands and boundary conditions in the case study communities to ensure long-term implementation of appropriate technologies and measures?

The central section of this thesis was looking at data, modelling frameworks and data processing or scenario building procedures. The central aim of the research question was to build a framework of data for small- and medium-sized communities to be integrated into the GIS model and the scenarios. For the central data section a selection of available technologies was chosen which had the greatest impact for the case study community. This was meant to facilitate the implementation and focus on the most relevant aspects with respect to the results of the first two sections of the thesis.

E How can GIS help to understand and analyse communal energy systems?

GIS-models are today used for numerous applications in the context of urban planning and energy potential mapping. In chapter four the available data framework of a GIS from an urban planning perspective was analysed and the cross-links to energy system analysis were identified. In the urban planning framework a lot of GIS compatible data is already in use and can be implemented easily in the new application. Since most energy issues are connected to spatial properties a geographic representation helps to understand and communicate the relationships between system components. The future possibilities for the use of GIS are manifold and need not necessarily result in conventional desktop solutions. Sharing information and easy access to specific information via geo-references and web-map solutions offer promising solutions for the communication and monitoring of energy transition projects.

F What central data characteristics describe the model community of the case study?

The case study community one the one hand represents a typical medium-sized rural community in Germany. On the other hand existing initiatives and implemented measures in the energy field make the community exceptional. In chapter five the developments of the case study were described to give an overview on the boundary conditions and previous developments under which the case study community has developed. This gives the necessary framework to evaluate and classify the results of chapter ten.

G What default energy system components can represent the communal energy system with sufficient accuracy?

This research question was covered in three chapters. Chapter six analysed the data situation for building an urban morphology model for energy transition. There is a good availability of default data from numerous studies although validation data is scarce and most studies use approximations of many kinds. The renewable potentials were covered in chapter seven. Here the default data is based mostly on climatic and environmental approximations and assumptions. Chapter eight covered the technologies which enable a better matching of the demand and the supply side. While there is a good default data on urban morphology and energy potentials from numerous studies, the data situation for all innovative system components are rather scarce. The compilation of a data set for an urban energy scenario model resembles a set of slides with information. Not like a jigsaw-puzzle, the slides of information overlap and there are missing gaps, so there is hardly an option to obtain a concise data set. Nevertheless there is enough data available to create a colourful picture with a good representation of the core elements. Nevertheless some more validated data especially on the existing building stock would be very useful.

H Is there a sufficient local data availability to create a specific model of the energy system?

Based on the default data compilation chapters six, seven and eight continued with the analysis of available specifications for the case study. Specific studies can make the data more meaningful for the modelling. Even in small communities there is specific data available that can be beneficial for the data framework. Often these data sources are scattered over several municipal institutions and need some persistence to be collected. The framework allows to replace default data with specific local information even on it is not complete or available for the entire community. By a good monitoring of the data origins a high level of transparency can be maintained. Each community has its own specific conditions. It is important to design the data framework without too much unavailable or unnecessary data queries. With the local data the model becomes a learning picture of the community which represents the progress also in data availability. The open structure allows implementing data from different sources as long as they comply with some geographic reference. The verification and on-site validation is time-consuming and probably one of the most costly steps in urban system modelling. In the future improved laser-scanning methods can facilitate the data building process.

I What principle scenario design is helpful to support communal energy transition processes?

While the aim of simulation is usually to create an 'as-good-as-possible' model of the problem of interest, scenarios are more vague and open regarding their limiting-curves. While the intention of simulation is a precise forecasting, scenario building is about the description of developments that may take place within the beam barriers of actions taken and decisions made. A clear differentiation between possible outcomes of simulation and scenario building is important to understand and weigh the outcomes of the two. Certainly scenarios can base on and integrate simulation models, some very complex approaches of integral system modelling have been described in chapter three, nevertheless the assumption of being able to precisely predict future developments if only the modelling incorporated more complex and dynamic system descriptions, has so far failed to meet the high expectations in practical application. At the same time models that contain a high level of mathematical precision and complexity are often avoided by decision-makers because of their high complexity and opacity. The scenario model tried here is, compared to some of the analysed sophisticated models, of only little complexity. The design of scenarios is important to show the results of certain developments over longer time-periods. The principles and existing approaches to scenario modelling were analysed in the first section of chapter nine from a literature study. In principle scenarios are used for different purposes and these follow their specific logic. It is important to clearly differentiate between the different scenario types because they are designed to serve different purposes and affect the system design differently. For the purpose of energy transition scenarios all three basic types of scenario models are suitable. The explorative scenarios which are mainly covering "What-if?" progressions are probably the most suitable for the range of measures communities can take influence on. The geographic dimension of the GIS display adds an additional layer of information to common scenario results. By creating a scaled picture of spatial consequences the message can become more striking and easily accessible.

J What adaptations are necessary for the design scenarios in the case study?

The specific scenario design for the case study was developed in the second part of chapter nine. Based on the findings of the first general section three different energy system scenarios and a base-case scenario were developed. The research question addresses the requirements of adjusting the scenario design to the local specifications be it energy potentials or policies. The adaptations mainly concerned the choice of appropriate scenario layouts to cover the development visions described in chapter two.

Summary of the findings

The research questions and results of this section cover the largest part of this thesis. Sub-question E was discussed in chapter four. Sub-questions F was covered in chapter five. The sub-questions G and H were the topic of chapter six and the sub-questions I and J were covered in chapter nine. A summary of the central findings is given in Table 12.3.

PRIMARY RESEARCH QUESTION	SECONDARY RESEARCH QUESTION	RESULTS SECONDARY RESEARCH QUESTION	RESULTS PRIMARY RESEARCH QUESTION
How can tools and models be adapted to the specific demands and boundary conditions in the case study communities to en-sure long-term implementation of appropriate technologies and measures?	E. How can GIS systems help to understand and analyse communal energy systems?	GIS offers a good visualisation and spatial representation of results. Existing GIS data can be used for energy models as well. GIS functionalities offer great development potential for future application extensions.	Open and modular tool architectures offer sufficient possibilities to integrate specific5 focal points. Flexible data models allow the integration of default and specific data with manageable requirements on consistency and completeness. Scenario modelling is an appropriate tool to approach energy transition processes with high demands for strategic decision making and communication.
	F. What central data characteristics describe the model community of the case study?	For interpretation of results the meta context of the community is important. This includes stakeholder analysis and process history. First step for the model and scenario design.	
	G. What default energy system components can represent the communal energy system with sufficient accuracy?	On the demand side the urban morphology is a central determinant. So is demography data. Default data is available for all relevant energy potentials but need specification. This is increasingly important for the synergy modules where even default data is scarce.	
	H. Is there a sufficient local data availability to create a specific model of the energy system?	Specific data is available but scattered. Collection and compilation takes time and needs professional handling. In combination with local project processes continuous data updates need to be handled and integrated in 'learning models'.	
	I. What principle scenario design is helpful to support communal energy transition processes?	Base types of scenarios serve different investigation purposes and need differentiation. predictive and explorative scenarios are well suitable for the purposes of energy system development analysis. These can be used either in a forecasting or back-casting mode.	
	J. What adaptations are necessary for the design scenarios in the case study?	Scenarios need to be adjusted to the local specifications and development visions. Specific indicators can contribute to the value of results.	

TABLE 12.3 Summary results primary and secondary research questions section three

TOC

§ 12.3.4 How does the practical implementation of the adapted tools work in the case study and what barriers must be overcome for long-term success?

This research question titles the final two chapters ten and eleven. For the case study of Wolfhagen the scenarios are filled with data and evaluated in chapter ten. All the assumptions and the design of the framework accumulate in this chapter. The research aim of the application was to finalise with the visualisation of the preceding work. Due to the project framework of this thesis described in chapter one, the final evaluation could not be discussed and evaluated with the community stakeholders. This will be a task for the future project handling. The findings regarding these final research questions are the discussion basis to evolve and roll-out the model in practice. To add some evaluation experiences to the thesis a comparable project could be found in the case study of the "100 % renewable island" of Samsø, Denmark. To learn from their experiences in the transition project and to contribute these experiences to this thesis, I was able to hold an interview with one of the central protagonists of the Samsø energy project Søren Hermansen. Aside from the inspiring conversation, I got the chance to visit some of the energy plants which were erected in the course of the project. The interview was focussed on the 'lessons-learnt aspects' and barriers as well as success factors as they were experienced on Samsø. The interview was evaluated in chapter eleven. The final results from the Dutch research project EOS-LT: TRANSEP-DGO was less focussed on implementation projects but more on the prior project developments, strategies and tools. The final outcome can be located very much at the same point this thesis ends. The needs and barriers at the pilot communities have been analysed. In corporative processes visions and strategies have been discussed with the stakeholder groups and a basic set of tools has been developed. The project has resulted in a network to spread the results and support practical implementation[53]. The results from the EOS project have contributed to the design of the model of this thesis. A final evaluation of the research project is given in 12.3.4. The secondary research questions are focussed on the application of the model and the realised transition projects.

K How does the scenario framework function in a practical case study application?

This secondary research question was the topic of chapter eight. From the design of the framework to the actual functioning of a model it is a rugged road. The chapter integrates the characteristics from chapters six to nine of the data section into the GIS platform and gives evaluation and representation examples. The results of chapter eight show that the application of the scenario model at this stage of development

53 See: http://www.platformdgo.nl

needs future development. The core GIS system is too complex for small- and medium-sized communities to handle themselves. As for urban planning tasks the energy transition model needs customised applications with configured functionalities. The common program framework allows the link to other GIS applications and data exchange. The options for future developments and an outlook are given in 12.3.2. A deficit of the GIS framework is the missing functionalities to display time-series. This means that the scenario modelling still has to bridge from reference year to reference year. Time-lapse and fast-motion functionalities could in the future create a more dynamic appearance of the results.

L Do the central outcomes and messages create a useful picture to support energy transition in the community?

The secondary research question is closely connected to the application of the model and was covered in chapter ten. While the first research question was concerned with the applicability of the model and the handling of the GIS framework, this research question addresses the results and outcomes. The central idea of the scenario definition was to create clear messages and show trends of the defined development paths. This was to fulfil the original requirement to support general strategy developments and communication in the communities. As chapter ten shows the scenarios are quite clear in their message and development direction. It became clear that the community has already proceeded to different stages regarding the scenario visions. While progress in the renewable energies scenario is already way advanced the progress in the other two scenarios is more inert and shows more revolving processes. The three scenarios represent the pros and cons described in chapter two quite well. The options for visualisation in the GIS framework are sufficient and the core messages can be transported. The indicator set visualises the developments in a simplified way.

M What lessons can be learned from the different transition projects?

To answer this final secondary research question a summing-up evaluation of findings from the case studies was done. The interview on the Samsø project was given in chapter eleven. Developments along the energy transition project in the case study of Wolfhagen have been discussed in chapter five. A central lesson from the experiences with the implementation is that missing tools are not the core barrier that prevents implementation. The central success factor for the initiation and realisation of long-term transition projects in small and medium-sized communities is the engagement of innovative people and communication. In this simplified scenario tools will find their proper scope of application. While in the Samsø project the tools were left solely in the hands of external engineers, the linkage of new energy transition applications to GIS-applications already in use, gives the strategic planning authority to the communities.

This still needs development work and testing of commercial applications but is in principle a promising solution. The idea to create a proper understanding of the energy system and to work on thinkable development scenarios for the internal communication process empowers communities to start and steer the project before external experts get involved.

Summary of the findings

The research questions and results of this final section have been discussed in chapter ten and eleven. The implementation of the theoretical data and scenario development to the case study situation was the central topic of chapter ten. The experiences from a more advanced case study in Denmark are the central research content of chapter eleven. A summary of the central findings is given in Table 12.4.

PRIMARY RESEARCH QUESTION	SECONDARY RESEARCH QUESTION	RESULTS SECONDARY RESEARCH QUESTION	RESULTS PRIMARY RESEARCH QUESTION
How does the practical implementation of the adapted tools work in the case study and what barriers must be overcome for long-term success?	K. How does the scenario frame-work function in a practical case study application?	Framework needs professional handling at this stage of development. Customised solutions have to be the next step for roll-out.	Scenario modelling creates a good overview on the potentials of energy transition in the communities. The concise data framework supports understanding of system interaction and dependencies. At this stage of develop-ment the tool needs professional handling but offers options for roll-out.
	L. Do the central outcomes and mes-sages create a useful picture to support energy transition in the community?	Messages of the scenarios are clear and trans-parent. Options for visualisation are good and can develop towards dynamic time-lapses.	
	M. What lessons can be learned from the different transition projects?	Tools are not core success factors for energy transition projects in small- and medium-sized communities. Scenario models are helpful to engage them in the process and increase their planning and steering autonomy.	

TABLE 12.4 Summary results primary and secondary research questions section four

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§ 12.4 Discussion

This thesis research started with the perception that small- and medium-sized communities have great potentials to become the game-changers in energy transition. On the other hand they lack personal capacities and simple tools to initiate strategic projects within the range of their planning authority. The established tools of integrated planning are not applied on a standardised basis and lack the customised decision support for energy transition projects. The PhD project addressed the challenges of energy transition from the perspective of urban planning and created an approach to fill the gap of decision support in energy transition projects for small- and medium-sized communities. In the project it was shown that it is possible to create a meaningful picture of the energy system of the community on the basis of available data. The framework was developed with an open architecture which allows the future extension of both energy sectors and complexity. The next challenging step is the practical application within the case study community in the course of the BMBF research framework and the evaluation and optimisation for long-term implementation. From this next step the knowledge transfer to other communities can proceed in the coming years.

Over the research period for this thesis the core theme has become clearer and the application needs more precise. The complexity of energy system transition in communities has set limits to the completeness of the solution I was able to deliver in the scope of this work. With the termination of this PhD project the discussion on better and faster implementation of energy transition in the real world is still in full swing. The results and the lessons learnt from this project are certainly useful to build future research upon and to address the challenges of practical implementation challenges.

§ 12.4.1 Limitations

The research of this thesis aimed at the development of improved tools and models on energy systems specifically for small- and medium-sized communities. The central aim was to bridge the existing gap between academic research on modelling and the needs of practical anchoring in the everyday planning practice in a rural community as the case study. Since energy systems encompass all of our daily lives the model covered in this thesis is not complete. The open framework architecture allows a modular extension of the scope and capacities of the approach.

1. Include other energy consumption sectors, especially transportation which accounts for large share of the total energy balance in communities.

2. Ensure long-term implementation of the model-tool architecture in the local planning department. This means the practical testing of the model on robustness, the ability to be adapted to new functionalities. This could not be tested and evaluated in this thesis. Also the involvement of stakeholders and interest groups still has to be tested. Depending on the future research results in this practical evaluation phase, the model will have to prove its adaptability.

3. Financial issues. The scenario model of this thesis did not cover the economic consequences of the scenarios. The model implies feasibility by focussing on state-of-the-art technologies in most scenario cases. A specific cost-benefit analysis was not covered. It is clear that the economic aspect is important to convince stakeholders to take the suggested measures.

4. Include data handling interfaces. To ensure easy access to the scenario model and successful long-term implementation input interfaces facilitate the handling tremendously. The interfaces should be as self-explanatory as possible and include plausibility checks and access to defaults data.

5. Data security and communication transparency. The high complexity of energy systems demands the integration of data from different sources. The sensibility of all personal consumption and consumer profile data is very high. The implementation of the model within the framework of urban planning and administration demands a concise data security management which has to be tested and throughout conform to legal requirements.

6. Improve modelling. The dynamic functionalities of the model at this point are rudimental. Especially for scenarios with greater emphasis on spatial and temporal congruence of demand and supply more dynamic modelling is necessary to achieve better results.

§ 12.4.2 Weaknesses of the approach

The model undoubtedly has some weaknesses that have their origin in the general topic and the methodology. In general it has to be stated that energy is still a B-priority problem for most people outside the professional sector. It is still quite difficult to create sustainable interest in energy transition processes. An exception is the direct personal involvement in the case of local measures, as for instance large-scale wind energy which triggers support or opposition. Since the personal dismay is even lower,

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issues of climate change are commonly no trigger for personal involvement either. This is the general weakness of any approach trying to create more understanding and transparency in energy transition projects. This has to be acknowledged when weighing the importance and potential impacts of new tools and models. Regarding the fight against climate change being a "super-wicked problem" (Wiesenthal 2010) it can be characterised by a complexity in factual and social dimension and a specific problem dynamic on the timescale which is not easy to represent nor to communicate. Early problem dampening measures may show a greater effect on the problem but lack an evident trigger, therefore they are often missed. This applies, regarding the effects on climate change, to most efficiency measures. Scenario modelling can contribute somewhat to a better understanding of these effects.

A weakness of the model and the framework in this PhD thesis is certainly the fact that I am lacking a professional background in GIS modelling and geo-processing but come from the planning disciplines. Because of this the powerful modelling and evaluation possibilities of geo-information systems were by far not encompassed in this project. To create an attractive fun-to-use self-explanatory tool for commercial application a great amount of programming and design work is still to be done. For this the help and support of GIS and communication professionals is necessary.

§ 12.4.3 Reflection on the research process

The layout and progress of this research suffered and profited to some extent from being located at the crosslink between research and practice. The 'reality' of finding feasible compromises between different stakeholders and political decision-makers added a good quantum of realism to the approach. The progress and demands of the project realisation as well were distractions from conducting the research work. The objectives of the case study research changed somewhat following political and investment preferences. The model had to some extent follow these shifts. This applied specifically for the case studies in the EOS-LT project, were the targets were not so clearly defined in the beginning. In a research environment stable boundary conditions definitely allow a more targeted approach. The link to practice makes changes in the research work plan necessary, leading to less well-structured research processes than usual in science. The work was primarily focussed on bridging the gap between research and practice in the field of energy transition. The link into practice can be regarded a necessary precondition for research projects that touch urban planning. The outcomes in this approach are hopefully not from the 'ivory tower' of research. Being employed in the field of applied science not in basic research the link between theory and practice seems the most promising way to achieve the targets stated for this work. The back side could be a disappointing overall result. Not complying with the

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high requirements and strict research plans of basic scientific research, nor fully ready for practical implementation. On the other hand both sides profit from the approach by taking a step towards each other and emphasising the fact that they are two sides of a coin. Only in the continuous strife to understand and comply with both sides the chances for development are maintained. This kind of research as well takes the risk of falling between all stools. The integrative and multidisciplinary character, aggregating and compiling key findings from different scientific fields leads to the problem that it cannot be put in a specific research 'box'. These are commonly much deeper than they are wide, while the approach of this thesis is probably more of the fishing net type. Quite some details certainly slipped through the loops which makes scientific discourse on the topic difficult. Linking energy concepts with scenario modelling and urban transition planning characterises the complexity of this rather cross-cutting than in-depth research work. Still the approach offered many unforeseen in-depth insights and findings on the way and might prove a good solution for complex 'fuzzy' problem statements in the planning disciplines.

§ 12.4.4 Outcomes and future application

The outcomes of the PhD project show that it is possible to create a good data basis and a solid framework for energy transition scenarios for small- and medium-sized communities on the basis of a GIS system architecture. The model shows the flexibility and adaptability to be transferrable from the case study to other communities as well. The communities have the option to adapt the scenario model to their specific needs and transition questions. To ensure practicability the model needs more testing in more pilot communities. The case study application and the integration into the long-term research project give good pre-conditions to proceed further towards an operational tool development. The trend of working with larger and more complex data in all fields of planning and communication is certainly a boundary condition under which the development of GIS based scenario modelling can evolve. The option to move applications from the desktops into the web offers potentials for a more cost-effective and easy-access implementation of these kinds of tools. Open-access mapping and the options to integrate large data sets as well as social media and communication tools still offers great potentials to bring energy transition issues closer to the people. To successfully go this way it is very important to differentiate clearly between the planning level which processes sensible personal data and a scenario model which can be based on default and aggregated data concepts. For the future application it is important to further develop the options which lay right at the cross-link of visualisation and an open communication between planning authorities and the public and the use of the model for planning and monitoring. To do this in the future application the model should be accessed from two levels: the planning authorities with their access to all sensible data in an 'expert' system and a communication platform accessible for the public via the internet which integrates all the information and social media tools. The GIS-based data model can supply both access ways with customised data frameworks and evaluation configurations.

§ 12.5 Final recommendations

The potentials of the outcomes of this thesis lie in the further development and future research opportunities to integrate new findings and better implementation within the framework model. The on-going research activity in the case study community offers possibilities to proceed with the work on the basis of this thesis. As next steps on the path towards implementation and improvement I would recommend the following:

1. Test the model design and the scenarios in close cooperation with the case study research team and integrate recommendations and specific needs into the framework. This can be done in the frame of workshops with the project partners to gather feedback.
2. Professionalise GIS-data model on a web-map basis with GIS developer to ensure compatibility with commercial applications and ensure a well working data architecture. The implementation of standardised processing and evaluation algorithms is a task as well.
3. Ensure data security on the border between expert-system and public showcase. The options for professional and open data integration have to be defined at this point and rules for data plausibility quick-scans and final checks have to be installed here.
4. Ensure the applicability in the planning authorities to ensure the long-term use and further development of the tool for planning and monitoring. This can be achieved by workshops with the local planning authorities to gather their recommendations and suggestions regarding the tool functions and scenario evaluation.
5. Test communication benefits. To fulfil the expectations of the model to support communication processes in the community the showcase has to be tested and run in the case study environment. As feed-back on the usefulness of information and the scenario messages feed-back from the local residents and stakeholders needs to be gathered. The effects on involvement and personal behaviour could be a valuable field for future research.
6. To test the feasibility of a roll-out and transfer of results to other communities a corporation with one or several new small communities would be very beneficial. This would add some new perspectives, new questions and development targets to the application of the scenario model. To take the step from scientific development into practice these kinds of beta-tests can deliver useful new information.

7 Finally the outcomes of on-going modelling research on single aspects of the scenario model should be tested on compatibility and options for integration. For instance in the field of refurbishment planning there are still many thinkable extensions for a useful combination of functionalities.
8 Stakeholders in small- and medium-sized communities should be encouraged by the outcomes of the thesis to take initial steps on the energy transition path, since the results that can be reached with state-of-the-art technologies is very encouraging.
9 Small- and medium-sized communities can benefit from numerous good and successful examples of front-runner communities whose boundary conditions are often very comparable.
10 Energy transition on a large scale depends on the local implementation. Despite the fact that public and scientific focus and attention is mostly on the mega-cities, it will be the countless small initiatives that will turn the tide.

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Summary

The necessity for transition in the energy sector is beyond dispute and high on the political agendas. Climate change, the depletion of fossil fuels and the vulnerability of economies to resource speculation and unreliable political systems in the producing countries lay path for a broad implementation of smart alternative solutions. This means the integration of more sustainable renewable energy sources in the existing supply structures or the displacement of existing systems by new ones. Cities and communities are central players in the energy transition process. Energy demand is determined by the built environment. Renewable energy production needs space. The conflicts between different interest groups often break out in the context of local implementation measures that affect urban planning and the appearance of landscapes.

Small- and medium-sized communities might prove to be game-changers in the overall energy transition because many problems have to be solved within their ambit. Urban planning is dealing with the numerous processes of urban change. Energy is a fairly new task to be addressed and many stakeholders lack experience and criteria for strategic decision making. After a period of fierce determination to turn the wheel against climate change, it seems that there is a growing resignation among politicians, planners and the public because some things have not turned out the way we'd expected and the hope for quick solutions fades. Rebound-effects seem to eat up the savings to a good extent, and alternative ideas of how sustainable energy systems may be put into place have not yet been persuasive in many cases. Energy systems have proved to be complex. They are still perceived to be important but in practice there is a growing uneasiness about the right steps to take.

The overarching research question of this thesis is: What do decision makers in small- and medium-sized communities need to become more successful in implementing energy transition processes? For the research project this general question was broken down into four primary research questions:

- How can communities anchor and monitor long-term energy transition visions in their communal development plans?
- What tools and models are available for urban energy system analysis?
- How can tools and models be adapted to the specific demands and boundary conditions in the case study communities to ensure long-term implementation of appropriate technologies and measures?

- How does the practical implementation of the adapted tools work in the case study and what barriers must be overcome for long-term success?

To answer these questions a combination of review of the current state of scientific literature of the thematic field with a practical application and evaluation of ‘real’ implementation projects was chosen. This appears to be a beneficial approach to scientific research in planning disciplines. The first research question is closely connected to urban planning and strategy. To anchor energy transition goals in these disciplines the potentials and consequences of political energy visions were studied. To monitor developments and progress existing indicator systems were reviewed and adapted to the needs of small- and medium-sized communities. For this overall target-definition the question of 'Exergy Thinking' in planning urban environments and energy systems was discussed. This basically means to create a deep understanding of the quality aspects in energy demand and supply systems and to be aware for better matching solutions. This approach opens many options for the integration of renewables in the heating and cooling supply. It showed that the definition of a clear long-term target or 'energy vision' supports the implementation of measures because it facilitates communication and controversy.

The large number of available tools and scientific methods for the analysis and optimization of communal energy systems was reviewed to answer the second research question. The results from this work mainly led to the one central challenge that has to be solved whenever complex modelling and strategic decision making are affected: Data. Data describes the status-quo and gives necessary information on the complex system interactions and influence factors. The options to create a concise data framework for the central objective were addressed in two steps. From literature, existing models and approaches general data frameworks were collected and summarized. Since the method was to be applied to the test case study the data was validated and tested under the case study conditions. This showed deviations and necessary specifications but as well a good analogy to the default data. From this a transparent and adjustable spreadsheet-model was developed to create scenarios for the case study and to answer the fourth research question. To create a holistic picture of the communal energy system and the effects of increased exploitation of renewables geographic information systems (GIS) show very valuable functionalities. Especially since the processing and interpretation of geographic information is anchored in urban planning disciplines and creates an easy access if energy system information is integrated. The open data architecture of GIS allows the integration of different data types as long as they have a spatial correlation. This enables to retrieve valuable results from a scenario model even with rather fragmented and incomplete data. To show the effects of different implementation strategies represented by the different 'energy visions' three energy scenarios were run for the case study. These three scenarios represent central 'beliefs' or ' approaches' in energy transition as well as overall development indicators and specific local aspects. Therefore the success of energy transition measures remains limited if not all essential development parameters take a favorable course.

The scenario evaluation shows some interesting results and shows the principal usability of the approach and the model. The base-case scenario shows that the community already reaches good results for the global energy indicators because of the existing measures. On a medium and long-term these measures are not sufficient though to stay on a good course. Especially the long-term developments in some cases produce unexpected results. For instance the rather unfavourable development of CO_2-emissions in the renewable energies scenario was not a predictable result at first glance. Here the effects of the chosen technologies and the effects of superior developments show their impact. As well the huge impact of the assumed efficiency measures was somewhat unexpected. Even though the assumed refurbishment rates do not exceed national recommendations and the efficiency qualities are far from passive-house standard, the efficiency scenario shows the fastest and best results for the global environment indicators. This can be explained by the fact that the demand reduction optimally complements the existing renewable energy strategy and can show its full potential in this combination. The results of the smart-city scenario show the expected and desired trends of a moderate and balanced long-term strategy that leads to a slower but continuous positive development in all the analysed energy system indicators. The long-term trends of the scenarios and the effects of following 'plain' strategies can be visualised well with the model and the developed scheme. Therefore the initial research questions can be answered positively. The framework gives good and useful results and offers many options for future extension. Certainly the next and most important aspect to include into the framework is the question of costs and economic effects. The overall investment and operational costs for the measures in the different scenarios will be very different. Efficiency measures especially in the existing building stock are costly while the costs for PV-plants will most probably further decline. This is certainly a shortcoming for the efficiency scenario. A future study could as well look at overall economic effects of the different strategies for the benefit of the community. Basic figures on the economic effects of renewable energy systems are already available (Hirschl *et al.* 2010) and could be implemented. This would certainly make the framework more beneficial for communal stakeholders. The model is transparent and simple enough to go this way in the near future and the achieved results of this thesis project are a good basis for this. The realisation of energy systems as sketched in the smart cities scenario still demands some changes in the regulatory boundary conditions and some new technologies mainly in the information and communication technologies. Smart and electricity grid compatible buildings which can contribute services in grid stability are an issue still to come and contribute to the integration of renewable electricity. The integration of renewable heat in communal supply systems is a big future opportunity to realise LowEx potentials in the heating and cooling sector. Stakeholders in small- and medium-sized communities should be

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encouraged by the outcomes of the thesis to take initial steps on the energy transition path, since the results that can be reached with state-of-the-art technologies are very encouraging. Energy transition on a large scale depends on the local implementation. Despite the fact that public and scientific focus and attention is mostly on the mega-cities, it will be the countless small initiatives that will turn the tide.

Samenvatting

De noodzaak van een energietransitie staat hoog op de politieke agenda. Klimaatverandering, het opraken van fossiele brandstoffen en de kwetsbaarheid van de economie voor speculatie en onbetrouwbare politieke systemen in de producerende landen banen de weg voor een brede implementatie van slimme alternatieve energiesystemen. Dit betekent de integratie van meer duurzame, hernieuwbare energiebronnen in het bestaande aanbodstructuren of de vervanging van bestaande systemen door nieuwe. Steden en kleinere gemeenschappen zijn centrale spelers in het energietransitieproces. De vraag naar energie wordt bepaald door de gebouwde omgeving. Hernieuwbare energieproductie heeft ruimte nodig. Conflicten tussen de verschillende belangengroepen breken vaak uit in de context van de lokale implementatie van projecten die de stedelijke planning en het uiterlijk van het landschap aantasten.

In de energietransitie zouden kleine en middelgrote gemeenschappen wel eens game changers kunnen blijken, omdat veel problemen moeten worden opgelost binnen hun invloedssfeer. Stedenbouw is het omgaan met de talrijke processen van stedelijke verandering. Energie is een tamelijk nieuwe taak voor de actoren en veel belanghebbenden hebben gebrek aan ervaring en criteria voor strategische besluitvorming. Na een periode van felle vastberadenheid om het tij te keren voor klimaatverandering, lijkt het erop dat er een groeiende berusting onder politici, planners en publiek ontstaat, omdat sommige dingen niet bleken uit te werken zoals we hadden verwacht en omdat de hoop op snelle oplossingen is vervaagd. Reboundeffecten lijken besparingen in belangrijke mate ongedaan te maken, en alternatieve ideeën over hoe duurzame energiesystemen kunnen worden gepositioneerd zijn in veel gevallen nog niet overtuigend geweest. Energiesystemen gebleken complex. Ze worden nog steeds beschouwd als belangrijk, maar in de praktijk is er een toenemende ongerustheid over de te nemen juiste maatregelen.

De overkoepelende onderzoeksvraag van dit proefschrift is: Wat hebben beslissers in kleine en middelgrote gemeenten nodig succesvoller te worden bij de uitvoering van energietransitieprocessen?

Voor het onderzoek werd deze algemene vraag onderverdeeld in vier primaire onderzoeksvraagen:

- Hoe kunnen gemeenschappen energietransitievisies op lange termijn in hun gemeentelijke ontwikkelingsplannen verankeren en controleren?

- Welke instrumenten en modellen zijn beschikbaar voor stedelijke energiesysteemanalyse?

- Hoe kunnen instrumenten en modellen worden aangepast aan de specifieke vragen en randvoorwaarden in de casestudiegemeenschappen om op lange termijn implementatie van geschikte technologieën en maatregelen te garanderen?

- Hoe werkt de praktische uitvoering van de aangepaste instrumenten in de casestudie, en welke hindernissen moeten worden overwonnen voor succes op lange termijn?

Om deze vragen te beantwoorden werd een combinatie gekozen van een evaluatie van de huidige stand van de wetenschappelijke literatuur van de thematische veld met een praktische toepassing en de evaluatie van de 'echte' implementatieprojecten. Dit lijkt een positieve benadering van het wetenschappelijk onderzoek in de planningsdisciplines. De eerste onderzoeksvraag is nauw verbonden met de stedelijke planning en strategie. Om energietransitie doelen in deze disciplines te verankeren werden de mogelijkheden en gevolgen van politieke energievisies bestudeerd. Om de ontwikkelingen en de voortgang te onderzoeken werden bestaande indicatorsystemen bekeken en aangepast aan de behoeften van kleine en middelgrote gemeenschappen. Voor deze algemene doelstelling werd de kwestie van 'exergiedenken' in de planning van stedelijke omgevingen en energiesystemen besproken. Dit betekent het krijgen van een diep begrip van de kwaliteitsaspecten van de vraag en het aanbod van energiesystemen en het zich bewust worden van betere afstemmingsoplossingen. Deze aanpak opent vele mogelijkheden voor de integratie van hernieuwbare energiebronnen in het aanbod van verwarming en koeling. Daaruit bleek dat de definitie van een duidelijke langetermijndoelstelling of energievisie de implementatie van maatregelen ondersteunt, omdat deze de communicatie en discussie vergemakkelijkt.

Het grote aantal beschikbare instrumenten en wetenschappelijke methoden voor de analyse en optimalisatie van de gemeentelijke energiesystemen werd beoordeeld op de tweede onderzoeksvraag te beantwoorden. De resultaten daarvan leiden naar het ene centrale probleem dat opgelost moet worden als complexe modellering en strategische beslissingen worden meegenomen: data. Data omschrijven de status quo en geven de nodige informatie over complexe systeeminteracties en invloedsfactoren. De opties om een beknopt datakader voor de centrale doelstelling te creëren werden in twee stappen onderzocht. Uit literatuur, bestaande modellen en aanpakken werden algemene data verzameld en samengevat. Aangezien de werkwijze zou worden toegepast op de casestudie zijn de data gevalideerd en getest onder de omstandigheden van de casestudie. Hieruit bleken afwijkingen en nodige specificaties, maar ook een goede analogie met de standaarddata. Hieruit werd een transparant en aanpasbaar spreadsheetmodel ontwikkeld om scenario's voor de casestudie te creëren en om de vierde onderzoeksvraag te beantwoorden. Om een holistisch beeld van het gemeentelijke energiesysteem en de effecten van de toegenomen exploitatie van hernieuwbare energiebronnen te creëren hebben geografische informatiesystemen (GIS) zeer waardevolle functionaliteiten. Vooral omdat het verwerken en interpreteren van geografische informatie in stedelijke planningdisciplines is verankerd en voor een gemakkelijke toegang zorgt als energiesysteeminformatie wordt geïntegreerd. De open data-architectuur van GIS laat de integratie van verschillende datatypen toe, zolang ze een ruimtelijke correlatie hebben. Dit maakt het mogelijk om waardevolle resultaten van een scenariomodel, zelfs met nogal versnipperde en onvolledige gegevens, op te halen. Om de effecten te laten zien van verschillende implementatiestrategieën, vertegenwoordigd door van de verschillende energievisies, werden drie energiescenario's uitgevoerd voor de casestudie. Deze drie scenario's vertegenwoordigen de centrale 'overtuigingen' of 'aanpak' in de energietransitie en de algehele ontwikkeling van indicatoren en specifieke lokale aspecten. Daarom blijft het succes van de energietransitiemaatregelen beperkt, indien niet alle parameters van essentieel belang een gunstig verloop nemen.

De scenario-evaluatie toont enkele interessante resultaten en toont de bruikbaarheid van de aanpak en het model. Het base-casescenario laat zien dat de gemeente, als gevolg van de bestaande maatregelen, voor de algemene energie-indicatoren al goede resultaten bereikt. Op middellange en lange termijn zijn deze maatregelen echter niet toereikend om op een goede koers te blijven. Vooral de ontwikkelingen op lange termijn produceren in sommige gevallen onverwachte resultaten. Bijvoorbeeld, de nogal ongunstige ontwikkeling van de CO_2-uitstoot in het hernieuwbare energiescenario was op het eerste gezicht niet een voorspelbaar resultaat. Hier tonen de effecten van de gekozen technologie en de effecten van superieure ontwikkelingen hun effect. De enorme impact van veronderstelde efficiencymaatregelen was eveneens enigszins onverwacht. Hoewel het veronderstelde renovatieniveau niet verder gaat dan de nationale regelgeving en de efficiencykwaliteiten verre van passiefhuis-standaard zijn, toont het efficiëntiescenario de snelste en beste resultaten voor de globale milieu-indicatoren. Dit kan worden verklaard door het feit dat de vraagreductie een optimale combinatie vormt met de bestaande strategie voor hernieuwbare energie en zijn volledige potentieel in deze combinatie kan laten zien. De resultaten van het smartcityscenario tonen de verwachte en gewenste ontwikkelingen van een gematigde en evenwichtige langetermijnstrategie die leidt tot een langzamere, maar continue positieve ontwikkeling in alle geanalyseerde energiesysteemindicatoren. De trends van de scenario's en de effecten van het volgen van strategieën voor de lange termijn kunnen goed worden gevisualiseerd met het model. Daarom kunnen de initiële onderzoeksvragen positief worden beantwoord. Het model geeft goede en bruikbare resultaten en biedt vele mogelijkheden voor toekomstige uitbreiding. Dat is zeker het meest belangrijke aspect om in het model op te nemen: de vraag van de kosten en de economische gevolgen. De totale investeringen en operationele kosten voor de maatregelen in de verschillende scenario's zijn heel verschillend. Efficiencymaatregelen zijn vooral in bestaande gebouwen duur, terwijl de kosten voor

PV-installaties waarschijnlijk verder zullen dalen. Dit is zeker een tekortkoming in het efficiëntiescenario. Een toekomstige studie zou ook kijken naar algemene economische gevolgen van de verschillende strategieën ten behoeve van de gemeente. Basiscijfers van de economische effecten van duurzame energiesystemen zijn reeds beschikbaar (Hirschl *et al.* 2010) en kunnen worden opgenomen. Dit zou het model zeker aantrekkelijker maken voor gemeentelijke belanghebbenden. Het model is transparant en eenvoudig genoeg om deze weg te volgen in de nabije toekomst en de behaalde resultaten van dit promotieonderzoek zijn hier een goede basis voor. Het realiseren van energiesystemen zoals in het smartcityscenario heeft nog een aantal wijzigingen nodig in de regelgevingtechnische randvoorwaarden en in nieuwe technologieën, vooral in de informatie- en communicatietechnologie. Slimme en elektriciteitsnetcompatibele gebouwen die diensten kunnen bieden in de netstabiliteit zijn een kwestie die nog kan bijdragen aan de integratie van hernieuwbare elektriciteit. De integratie van duurzame warmte in gemeenschappelijke leveringssystemen is een grote toekomstige kans om het LowEx-potentieel in de verwarmings- en koelingssector te realiseren. Belanghebbenden in kleine en middelgrote gemeenten kunnen worden aangemoedigd door de resultaten van het proefschrift, om de eerste stappen op de energietransitieweg te zetten, aangezien de resultaten die kunnen worden bereikt met state-of-the-art technologieën zeer bemoedigend zijn. Energietransitie op grote schaal is afhankelijk van de plaatselijke uitvoering. Ondanks het feit dat de aandacht van het publiek en de wetenschap meestal op de megasteden is gericht, zullen het de talloze kleine initiatieven zijn die het grote verschil zullen maken.

Zusammenfassung

Die Notwendigkeit einer Energiewende steht außer Frage und hoch auf den politischen Agenden. Der Klimawandel, schwindende fossile Ressourcen und die Verwundbarkeit der globalen Ökonomien gegenüber Rohstoffspekulationen und unzuverlässigen politischen Systemen in den Förderländern bahnen den Weg für innovative Alternativlösungen. Dies bedeutet eine verstärkte Integration von nachhaltigen erneuerbaren Energieträgern in die bestehenden Versorgungssysteme und den Ersatz bestehender Systeme durch neue. Städte und Gemeinden sind zentrale Akteure in der Energiewende. Der Energiebedarf wird maßgeblich durch die gebaute Umgebung geprägt. Erneuerbare Energien beanspruchen Flächen. Konflikte zwischen den verschiedenen Interessensgruppen treten häufig im Zuge der lokalen Umsetzung von Maßnahmen auf, wenn der städtische und landschaftliche Raum verändert wird.

Kleine und mittelgroße Kommunen könnten sich als die Schlüsselakteure erweisen, da viele Probleme innerhalb ihrer Zuständigkeitsbereiche gelöst werden müssen. Die Stadtentwicklung beschäftigt sich mit einer Vielzahl von städtischen Veränderungsprozessen. Energie ist hierbei ein verhältnismäßig neuer Aufgabenbereich und vielen Entscheidungsträgern fehlen die Erfahrung und solide Kriterien für die strategische Entscheidungsfindung. Nach einer Phase großer Entschlossenheit, den Klimawandel zu stoppen, scheint sich inzwischen eine gewisse Resignation bei Politikern, Planern und der Öffentlichkeit breit zu machen, da manches nicht wie gewünscht umgesetzt werden konnte und die Hoffnung auf schnelle Lösungen zunehmend schwindet. 'Rebound-Effekte' scheinen einen großen Teil der Einsparungen aufzuzehren und alternative Ideen zur Umsetzung nachhaltiger Energiesysteme haben in vielen Fällen nicht überzeugt. Energiesysteme erweisen sich als komplex. Nach wie vor wird die Energiewende als wichtiges Thema gesehen, wobei sich um die richtigen Umsetzungsschritte ein wachsender Dissens zeigt.

Diese Arbeit beschäftigt sich der Frage, was Entscheidungsträger in kleinen und mittelgroßen Kommunen benötigen, um einen erfolgreichen Energiewendeprozess zu initiieren und umzusetzen. Auf Basis dieser sehr allgemeinen Fragestellung wurden vier primäre Forschungsfragestellungen formuliert:

- Wie können Kommunen langfristige Energiewendevisionen in ihren strategischen Entwicklungsplänen verankern?

- Welche Werkzeuge und Modelle sind für die Analyse kommunaler Energiesysteme einsetzbar?

- Wie können Werkzeuge und Modelle auf die spezifischen Anforderungen und Randbedingungen der Testkommunen angepasst werden, um eine langfristige Umsetzung geeigneter Maßnahmen und Technologien zu erreichen?

- Wie funktioniert der Einsatz der adaptierten Werkzeuge in der Testkommune und welche Hemmnisse müssen für den langfristigen Erfolg noch überwunden werden?

Um diese Fragen zu beantworten, wurde eine Kombination aus wissenschaftlicher Literaturrecherche, praktischer Anwendung und Auswertung des Modells in der Testkommune gewählt. Dies schien ein vielversprechender Ansatz für eine wissenschaftliche Arbeit in einer Planungsdisziplin zu sein. Die erste Forschungsfragestellung ist eng mit einer städtebaulich-strategischen Entwicklungsplanung verknüpft. Um Fragen der Energiewende in dieser Disziplin besser zu verankern, wurden die Potenziale und Wirkungen von politischen Visionen als Leitmotive der Entscheidungsfindung untersucht. Um Entwicklungen nachzuverfolgen und zu bewerten, wurden bestehende Indikatorensysteme analysiert und auf den Bedarf kleiner und mittelgroßer Kommunen angepasst. Als ein mögliches Leitmotiv wurde der 'Exergieansatz' auf seine Anwendbarkeit in städtebaulichen und energetischen Planungsprozessen untersucht. Im Kern bedeutet dies, ein tieferes Verständnis für den thermodynamisch-qualitativen Aspekt in energetischen Bedarfs- und Versorgungsystemen zu erreichen und so zu nachhaltigeren Versorgungslösungen zu kommen. Die Berücksichtigung der Exergie als Optimierungsgröße ermöglicht eine besser Integration erneuerbarer Energiequellen zur Heizung und Kühlung. Es hat sich gezeigt, dass die Definition eines klaren, langfristigen Ziels oder einer 'Energie-Vision' die Umsetzung von Maßnahmen fördert, da die Kommunikation und der Diskurs ermöglicht und fokussiert wird.

Die große Zahl verfügbarer Werkzeuge und wissenschaftlicher Methoden zur Analyse und Optimierung wurde zur Beantwortung der zweiten Fragestellung in einer Querschnittsanalyse ausgewertet. Die Ergebnisse führten im Kern zu einem zentralen Problem, welches in Verbindung mit komplexen Modellen und strategischen Entscheidungsprozessen gelöst werden muss: die Datenverfügbarkeit. Daten beschreiben den aktuellen Zustand eines Systems. Sie liefern Informationen über die komplexen Systemzusammenhänge und Einflussfaktoren. Die Möglichkeiten, ein stimmiges Datengerüst zur Problemlösung zu erhalten, wurden in zwei Schritten untersucht. Aus der bestehenden Modellen und Methoden wurden Standardwerte ermittelt und zusammengefasst. Da der Ansatz in der Testkommune Anwendung finden sollte, wurden die Standardwerte anhand der verfügbaren Realdaten der Testkommune getestet und validiert. Hier zeigten sich Abweichungen und erforderliche Spezifikationen ebenso wie eine grundsätzlich gute Übereinstimmung mit den Literaturwerten. Auf dieser Basis wurde ein nachvollziehbares und anpassungsfähiges Szenariomodell für die Testkommune erstellt, um die vierte

Fragestellung zu beantworten. Um ein ganzheitliches Bild des kommunalen Energiesystems und der Auswirkungen einer verstärkten Nutzung erneuerbarer Energieträger zu erhalten, bieten geografische Informationssysteme (GIS) sehr vielversprechende Funktionalitäten. Insbesondere da die Arbeit mit geografischen Informationen bereits in den städtebaulichen Planungsdisziplinen verankert ist, bieten sie einen leichten Zugang zu zusätzlichen energetischen Informationen. Die offene Datenarchitektur eines GIS erlaubt die Darstellung verschiedener Datentypen, solange ein räumlicher Bezug hergestellt werden kann. Dies erlaubt es aus einem Modell auch dann wertvolle Informationen zu ziehen, wenn die Datenlage eher fragmentiert und unvollständig ist. Um die Auswirkungen verschiedener Umsetzungsstrategien exemplarisch zu zeigen, wurden die drei exemplarischen Entwicklungsvisionen in drei Szenarien für die Testkommune übertragen. Diese drei Szenrien repräsentieren grundlegende Herangehensweisen an die Energiewende und berücksichtigen allgemeine Entwicklungsindikatoren sowie lokale Gegebenheiten. Die Maßnahmen zur Energiewende bleiben in ihrem Erfolg begrenzt, sofern es nicht gelingt alle Entwicklungsparameter in eine positive Richtung zu lenken.

Die Auswertung zeigt neben der grundsätzlichen Brauchbarkeuit der Methode und des Modells einige interessante Ergebnisse. Das Referenzszenario belegt, dass die Kommune aufgrund der bereits umgesetzten Maßnahmen gute Ergebnisse bei den globalen Energieindikatoren erzielt. Mittel- und langfristig reichen diese Maßnahmen jedoch nicht aus, um auf dem Zielpfad zu bleiben. Insbesondere die langfristigen Entwicklungen weisen in einigen Bereichen überraschende Ergebnisse auf. Beispielsweise war die eher ungünstige Entwicklung der CO_2-Emissionswerte im Erneuerbare-Energien-Szenario auf den ersten Blick nicht diesem Umfang zu erwarten. Hier zeigen sich die Auswirkungen der gewählten Technologien in Verbindung mit den Auswirkungen übergeordneter Einflussfaktoren. Ebenso war der Einfluss der angesetzten Einsparmaßnahmen überraschend groß. Obwohl die angenommenen Sanierungsraten den nationalen Ansätzen entsprechen und die erreichte Gebäudeeffizienz deutlich über dem Passivhausstandard liegt, zeigt das Effizienz-Szenario die schnellsten Erfolge bei den globalen Energieindikatoren. Dies kann durch die Tatsache erklärt werden, dass die getroffenen Einsparmaßnahmen in idealer Weise den bereits erfolgten Ausbau der Erneuerbaren Energien ergänzen. Die Ergebnisse des Smart-City Szenarios zeigen die erhofften Entwicklungen einer moderaten aber kontinuierlichen Verbesserung bei allen berücksichtigten Indikatoren. Die langfristigen Entwicklungstrends und die Auswirkungen der typologischen Strategien lassen sich mit dem Model und dem entwickelten Verfahren gut darstellen. Aus diesem Grund kann die Forschungsfragestellung diesbezüglich positiv beantwortet werden. Das Konzept liefert gute und brauchbare Ergebnisse und hält viele zukünftige Erweiterungsmöglichkeiten offen.

Ein besonders wichtiger und anstehender Schritt ist die Integration von Kosten und ökonomischen Effekten in das Modell. Die notwendigen Gesamtinvestitionen und Betriebskosten der Maßnahmen in den Szenarien sind sehr unterschiedlich. Effizienzmaßnahmen insbesondere im Gebäudebestand sind teure Maßnahmen, wohingegen die Preise für Photovoltaikanlagen voraussichtlich noch weiter fallen werden. Dies stellt in der Praxis sicherlich eine Schwäche des Effizienzszenarios dar. Zukünftige Untersuchungen sollten sich zudem mit den ökonomischen Auswirkungen der verschiedenen Strategien auf die Kommune beschäftigen. Standardwerte zu den ökonomischen Auswirkungen erneuerbarer Energien finden sich zum Beispiel bei Hirschl *et al*. (2010). Diese könnten integriert werden. Damit würde das Konzept nochmal deutlich an Wert für kommunale Entscheidungsträger gewinnen. Das Modell ist transparent und offen genug, um dies in der nahen Zukunft anzugehen und die geleistete Forschungsarbeit liefert hierfür eine sehr gute Grundlage. Die Umsetzung des Energiesystems aus dem Smart-City Szenario erfordert noch einige Veränderungen in den regulatorischen Rahmenbedingungen und der Technologie. Insbesondere bei Schnittstellen und Informationstechnologien besteht noch Innovationsbedarf. Netzreaktive Gebäude, die zur Stabilisierung des Netzes und zum lokalen Lastausgleich beitragen können befinden sich noch in der Entwicklung. Der verstärkte Einsatz erneuerbarer Wärme in kommunalen Versorgungssystemen bietet zukünftig die Chance, Niedrigexergiepotenziale für die Heizung und Kühlung zu erschließen. Entscheidungsträger sollten sich durch die Ergebnisse der Arbeit darin bestätigt sehen, dass es sich bereits heute mit verfügbaren Technologien lohnt, die lokale Energiewende anzugehen. Die Energiewende im Großen hängt von den Erfolgen im Kleinen ab. Auch wenn die öffentliche und wissenschaftliche Aufmerksamkeit oftmals bei den glitzernden Mega-Städten liegt, so werden doch die unzähligen kleinen Initiativen letztendlich das Blatt wenden.

Curriculum Vitae

Christina Sager-Klauß was born on June 24th 1975 in Müllheim, Germany. She graduated from the Paul-Klee-Gymnasium Overath in 1994 after spending one year at different high-schools in the U.S. She studied at the faculty of architechture of the University of Kassel from 1994 until 2002. For her diploma thesis she modelled the effects of building constructions and façade concepts for offices on indoor comfort and energy efficincy.

After her studies she started her professional career as scientific employee at the Faculty of Architecture of the Technical University of Munich at the department of building climatology and building services. There she focussed on the development of innovative building design and efficient and renewable energy supply. The findings were published in 2005 in the handbook "Climate Design. Solutions for buildings that can do more with less technology".

From 2005 to 2007 she worked for the German Energy Agency in Berlin in the Department Building Energy Efficiency in international projects on the implementation of EPBD Energy Certificates.

In 2007 she returned to Kassel to continue her scientific career with the Fraunhofer Institute of Building Physics. Here she started to work with the exergy concept as guiding principle for sustainable and renewable energy systems on a community and district level. In 2008 she became group manager of the research group "Low-exergy-systems". The group is working in numerous national and international research projects in the field of energy effiency, renewable energy supply and energy transition for utilities, communites and cities. In 2015 her group was renamed in Buildings - Districts - Cities.

In 2009 she started her PhD project at the University of Technology Delft in the scope of the project "TRANSEP-DGO: Transitie in energie en process voor duurzame gebiedsontwikkeling". She was supported by the Fraunhofer program for female doctoral candidates and is member of the SciMento Mentoring program of the State of Hessen. Her defense will be held on 20th April 2016.

Christina Sager-Klauß is married and has three sons.

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