Analysis and Implementation of a Building Energy System Transformation

Masterarbeit

zur Erlangung des akademischen Grades „Master of Science (M. Sc.)“ im Studiengang Wirtschaftswissenschaft der Wirtschaftswissenschaftlichen Fakultät der Leibniz Universität Hannover

vorgelegt von

Name: Herbst Vorname: Roman

[redacted] [redacted] [redacted] [redacted]

Prüfer: Prof. Dr. M. H. Breitner

Ort, den: Hannover, den 30.09.2019

Contents

1 Introduction

Our current standard of living ensures that the demand for energy and the use of energy are increasing more and more: be it for example in the context of energy services and manufacturing processes in industry, for the provision of communication and information against the background of increased mobility and increasing traffic - or within the building sector because here above all the heating of rooms, water heating, light, electricity or the operation of other household appliances consume large amounts of energy. Accordingly the building sector is currently responsible for around 35 percent of total energy consumption in Germany and for 30 percent of energy-related carbon dioxide emissions (Bundesministerium für Wirtschaft und Energie 2017 pp. 35, 38). The construction and real estate sector is thus one of the largest national resource consumers and carbon dioxide (CO_2) producers (Pehnt 2010 p. 199).

Traditional energy production for example from fossil fuels such as heating oil and natural gas or from nuclear power inevitably goes hand in hand with potential environmental impacts and influences which are increasingly less tolerated in our sensitised society. There are national and even global energy technology and energy policy environmental debates about particulate matter and greenhouse gases are accordingly placing climate change, resource consumption, energy efficiency and future-oriented sustainability efforts at the centre of public awareness (Kaltschmitt et al. 2013 pp. 2, 9 ff.).

Last but not least, the Fridays for Future movement, initiated by the student Greta Thunberg, has emphatically demonstrated the urgency of implementing energy-efficient measures. Although climate change has been a collective issue for some time, it is amazing how one person has managed to put this existing issue and the urgency of tackling it back on the political agenda. This development becomes very clear from a current Google Trends survey, which is shown in the figure 1.
In this respect, Greta Thunberg presents herself as a driver of a social debate about the sustainability of the actions of each of member of society. It is also not surprising that it is above all young people who demand environmentally conscious action from not only from political actors but from society as a whole. The energy and climate policy goals of the United Nations, the European Union and Germany are important and necessary for the future of our planet, our country and for future generations, but in detail and in practice not easily realizable political objectives (Grothe and Zinnöcker 2018 p. 73).

Because of the continuing climate change those objectives must be met, which poses numerous challenges at the practical implementation level, which must be dealt with using the right innovative political and practical approaches if there is to be a future worth liv-

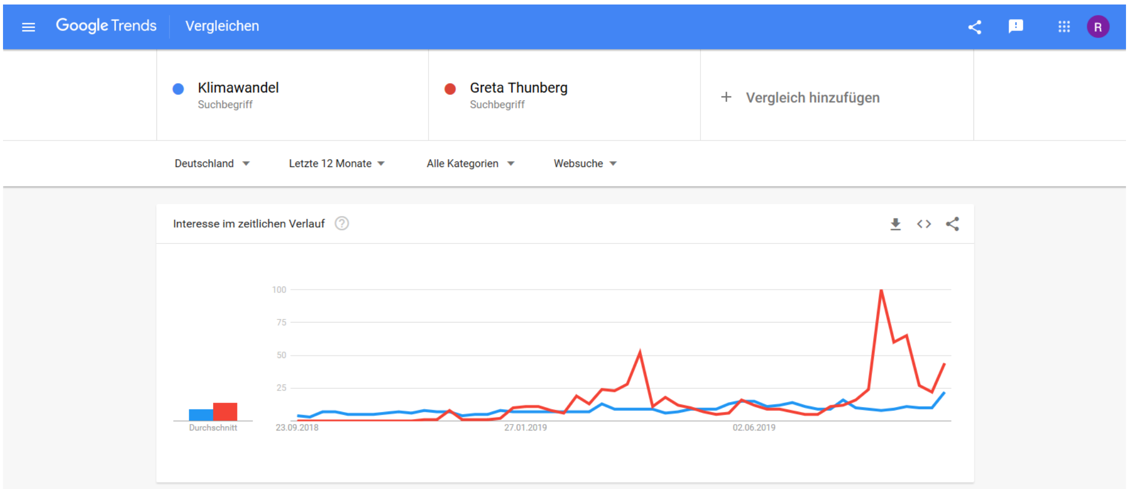

Figure 1 Google Trends queries in comparison: Greta Thunberg and climate change, source: own work based on Google Trends 2019

ing for mankind (Grothe and Zinnöcker 2018 p. 73).

The climate policy goals in Germany can be see in the planned energy system transformation which is based mainly on two different strategies. The first strategy relates to expanding the use of renewable energy sources and the second to increasing the energy efficiency of the energy supply system (Günther 2015 p. 11). This is supposed to make it feasable to reduce or eliminate the use of fossil and nuclear energy resources for which the Federal Government adopted the "Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung" [Energy Concept for an Environmentally Friendly, Reliable and Affordable Energy Supply] in 2010 (Günther 2015 p. 11).

Emissions of climate-relevant gases, especially CO_2, can be reduced above all by decarbonising the energy industry, i.e. the use of carbon-containing energy sources must be eliminated (Günther 2015 p. 11). By reducing the consumption of coal, crude oil and natural gas through the use of renewable energy sources, greenhouse gas emissions can be effectively reduced (Günther 2015 p. 32).

During the ongoing climate change debate the real estate sector has also been the focus of attention when it comes to needing to reduce their energy consumption. Accordingly the Institut für Öffentliche Wirtschaftsförderung (IÖW) has demanded the real estate sector to cut back on energy consumption seeing as around on third of the total energy consumption is needed to heat buildings and generate hot water (Weiß, Bost, and Dunkelberg 2017 p. 2).

The wishes and demands of building owners with regard to building energy systems are also increasingly revolving around criteria such as energy and cost efficiency, sustainability, conservation of resources and the use of renewable energies. According to a representative Forsa survey of 2018 this applies to the vast majority of potential house builders for whom low operating costs remain the most important criterion in the long term even with all energy efficiency and sustainability. For almost all respondents (95 percent) is it crucial that a sustainable building remains affordable overall, despite all its advantages. 94 per cent attribute high importance to low long-term expenditure on energy, maintenance and refurbishment. In addition 70 percent now consider it important to be able to supply the house to a large extent with self-produced green electricity in order to become more independent of conventional suppliers with household electricity and self-produced heating energy (Deutsche Fertighaus Holding AG 2018 p. 1). The economically profitable transformation of building energy systems into minimised energy consumption and the use of ecological, sustainable energy sources is therefore inevitable for an energy and environmentally conscious future of the building sector (Kaltschmitt et al. 2013 pp. 2, 9 ff.).

1.1 Problem Definition: The Heat And Energy Turnaround In Germany

For some years now politicians have also been devoting themselves to the ecological generation of energy and the reduction of energy and heat consumption in buildings. This development began with the Wärmewende [thermal sustainable energy transition]. On 1 November 1977 the so-called "Verordnung über energiesparenden Wärmeschutz bei Gebäuden (Wärmeschutzverordnung)" which was an ordinance on energy-saving thermal insulation of buildings came into force (Deutsche Energie-Agentur GmbH 2018 p. 9). For the first time it formulated mandatory minimum requirements for exterior building components which had to be observed with regard to thermal insulation, density, etc. By means of structural measures energy consumption was to be reduced not least in view of rising energy prices (Deutsche Energie-Agentur GmbH 2018 p. 9).

Of the approximately 19 million existing buildings in Germany today however around 12 million were built before this first thermal insulation ordinance came into force. For these buildings compliance with minimum energy standards during construction was not obligatory under regulatory law and only in regards to the framework of the technical regulations (DIN 4108). The thermal insulation requirements were therefore extremely low or non-existent (Deutsche Energie-Agentur GmbH 2018 pp. 9, 23).

The improvement of thermal insulation in buildings (for example with the help of special insulating materials or windows) was and is therefore a very important pillar of the integral energy turnaround as heat supply still accounts for the largest energy requirement in percentage terms: 78 percent of total energy consumption is accounted for by space

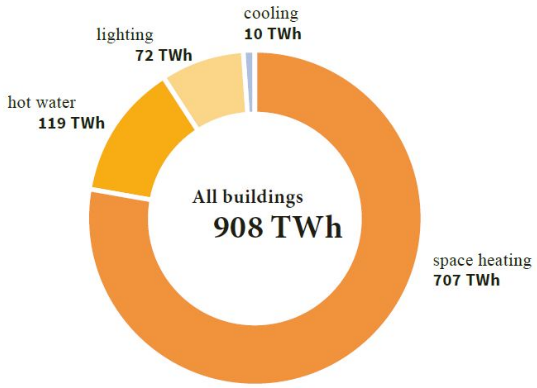

Figure 2 Current energy related building energy consumption in Germany, source: own work based on Deutsche Energie-Agentur GmbH 2018 p. 18

heating, hot water is responsible for 14 percent, see figure 2.

For the year 2020, the Federal Government of Germany has set itself the target of saving 20 percent in heating requirements compared to 2008 (Deutsche Energie-Agentur GmbH 2018 p. 27, Deutsche Umwelthilfe 2017a p. 2).
But the Federal Government has also set itself the goal of reducing the overall primary energy requirement of buildings by 80 percent by 2050. (Bundesministerium für Wirtschaft und Energie 2017 p. 58). This also requires the use of other technological innovations in building refurbishment and the gradual transformation of the entire energy systems of existing buildings in such a way that optimum energy efficiency and maximum use of renewable energies are specifically promoted and the individual components are profitably combined.

Renewable energies such as wind or water power, biomass, photovoltaics or similar are still only used to a comparatively small extent for space heating, hot water and other forms of final energy consumption - even though they have already become a visibly important source of energy for electricity generation in recent years (Deutsche Energie-Agentur GmbH 2018 p. 28) as shown by figure 3.
In figure 4 the final energy consumption in Germany by sector in TWh - i.e. in industry, business, transport and private households is shown.

In the end the energy turnaround would not only minimize the heat loss via the building envelope but rather the required energy would be generated in a completely climate-neutral way. Integrated, energetic refurbishment measures therefore include the energetic refurbishment of the building envelope and also range from the use of renewable energies and climate-neutral energy sources such as geothermal energy, waste heat or solar energy systems to the introduction of heat and electricity storage systems that balance the fluctu-

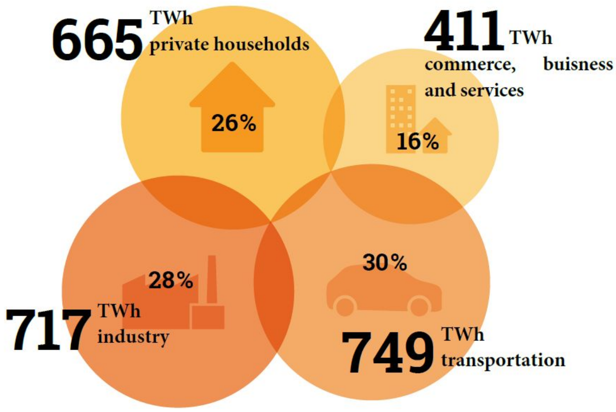

Figure 3 Final energy consumption by energy source in Germany, source: own work based on Deutsche Energie-Agentur GmbH 2018 p.26

ating demand for electricity and the installation of energy-efficient network technologies. Every energetic renovation must therefore take a holistic view of electricity and heat in all four stages - generation, distribution, storage and consumption - and optimise them accordingly (Deutsche Energie-Agentur GmbH 2018 pp. 10, 15).

As studies by the Federal Ministry of Economics and Energy (BMWi) have shown, within the framework of existing buildings (with their generally very high energy consumption compared to new buildings), private households in particular have a great potential for energy savings: not only were around 62% of the total private living space built before the first heat insulation ordinance came into force but most of it does not meet the requirements of the current Wärmewende. In addition the share of private households in final energy consumption is currently 26 percent (Deutsche Umwelthilfe 2017a p.2) as can be seen in figure 4.

According to research by the Institut Wohnen und Umwelt 25-30 percent of these existing buildings have already been modernised in terms of energy efficiency. In the real estate sector absolute greenhouse gas emissions were already reduced by 43 percent between 1990 and 2014 in accordance with the 2050 climate protection plan whilst at the same there was an increase in living space of 36 percent (Gedaschko 2018 p. 70). From 1990 to 2015, the housing industry reduced the specific CO_2 emissions for heating and hot water generation in its current stock by around 60 percent (Gedaschko 2018 p. 70).

In this sense the building sector is one of the main pillars of the energy turnaround, because without this area the turnaround will hardly be possible. The current stock of housing will in the future both function as an energy producer and an energy storage (Hauser 2012 p.139).

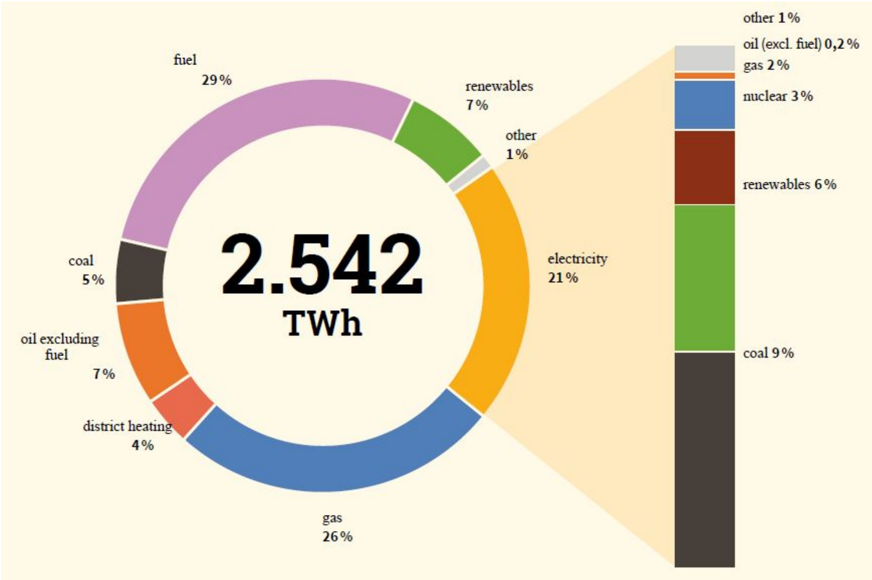

Figure 4 Final energy consumption in Germany by sector in TWh, source: own work based on Deutsche Energie-Agentur GmbH 2018 p. 25

However every second residential building in Germany still has inadequate thermal insulation and uses non-renewable energies (Deutsche Umwelthilfe 2017a p. 2). In addition to the energetic refurbishment of the existing building shell the efficiency of the system and the rate of use of renewable energies must also be improved in the future (Deutsche Energie-Agentur GmbH 2018 pp. 16, 25). This demand also makes it clear that what has been achieved so far is not sufficient to achieve the climate protection goals that Germany has set out to achieve and which are needed in order to reduce the impact of climate change. Change must be urgently implemented to achieve the long term goals.

In order to meet the German government's goal of achieving an almost climate-friendly building stock by 2050 the renovation rate for private existing residential buildings which is currently less than one percent must be specifically increased to at least two percent annually (Deutsche Umwelthilfe 2017a p. 2). For this however it is an important prerequisite to motivate private apartment and house owners to implement energy-efficient refurbishment - in other words, to demonstrate the economic viability of transforming the building energy system. Whether and when the energetic renovation is worthwhile for the owner however depends on many factors and cannot therefore be said in general terms (Deutsche Umwelthilfe 2017a p. 2).

1.2 Goal, Approach And Target Group Of The Work

Accordingly this thesis paper will focus on the requirements, possibilities and potentials as well as the economic viability analysis with regard to the conversion of a building energy system to renewable energies. Based on a comprehensive literature analysis a description of the various transformation approaches and components will be given while pointing out economic and political influencing factors and present economic assessment measures in the context of energy systems. In a simple scenario analysis potential transformation paths will also be presented as examples whereby information will also be given on whether they are not only ecologically but also economically sensible.

After a brief overview of the current explosive nature of the energy and climate targets at international, european and national level the central terms "energy consumption, energy efficiency and renewable energies will therefore be clarified at the beginning and some very general requirements and trends in the context of the conversion of a building energy system will be described.

This will be followed by an explanation of overarching strategies for the ecological and economic conversion of the energy system such as decarbonisation, energy efficiency improvement, sufficiency strategy and regionalisation. On the other hand individual exemplarily selected transformation components and approaches of a building energy system will be explained in more detail. These approaches which can be used for greater energy efficiency and sustainability in the construction sector include building insulation and lighting, heat and energy storage, the use of a condensing boiler or combined heat and power as well as the use of energy-efficient air-conditioning technology, a heat pump or a photovoltaic system.

Subsequently some of the exogenous (market) economic and political influencing factors and regulations which ultimately influence the feasibility and profitability of the individual transformation measures will also be dealt with using legal texts. These include, for example a CO_2 tax, the Renewable Energy Sources Act (EEG) and the creation of building standards. Available federal and state subsidies such as the various KfW subsidies, the CO_2 building refurbishment programme and the use of energy consultants will also be discussed shortly.

After a brief introduction to the importance of investment cost accounting, a few examples of selected economic valuation methods will then be explained in more detail. The focus here is on the internal rate of return (IRR) method, the levelized cost of energy (LCOE) and the energy return on investment (EROI).

Within the framework of a small scenario analysis, which is carried out using the "NESSI - Nano Energy System Simulation" software, it is then necessary to analyse a fictitious scenario as an example. In the course of the analysis different transformation paths with regard to the conversion to renewable energies are shown, which are evaluated afterwards in regards to their economic performance. Based on this, a scenario for the transformation of a building energy systems can then be formulated depending on recommendations and limitations.

At the end of the work follows a short summary and a look at the broader depth of the topic of building energy systems. In this context it is briefly hinted at that it is necessary to consider and optimize the building life cycle and the complete ecological balance of a building beyond the energy system changeover.

The research question for this scientific investigation is therefore as follows: Which criteria and analyses are of importance for the construction of a sustainable building energy system and how could such steps be implemented? Homeowners primarily carry out individual measures with manageable investment costs. Comprehensive renovation packages tend to deter them. Especially in the case of step-by-step renovation, it is important to draw up an overall concept in advance so that the individual measures can be built on one another in a meaningful way. The goal should always be to achieve the highest possible increase in efficiency with a limited budget. (Weiß, Bost, and Dunkelberg 2017 p. 6).

Accordingly this work primarily addresses energy planners, energy consultants as well as property owners, people interested in renovation and building owners who want to build and live energy-efficiently and ecologically according to future-oriented standards and want to transform existing building energy systems for this purpose and academics with a research interest in those areas. However, it is also aimed at all other interested parties, such as from energy and construction sectors, the economy and energy and climate policy, as well as all those active in existing buildings and energy-related renovation, who are affected in their work by the climate objectives and energy laws mentioned, the climate-neutral energy sources and energy system components or the economic consideration of an energy conversion and who deal with the topics of energy and cost efficiency as well as economic efficiency and sustainability.

9 Conclusion And Outlook: The Life Cycle Assessment Of Buildings

The officially adopted climate targets up to the year 2050 aim, among other things, at a complete emission-free stock of buildings, which should now be implemented in Germany as quickly as possible with the help of holistic, i.e. integral and interdisciplinary, energetic renovation measures. In essence, the concepts and regulations at EU and national level therefore primarily address the sustainable transformation of energy systems in the building sector towards the increased use of renewable energy sources (Hook 2018 p. 21 ff.). From the minimization of the energy requirement by an improved building insulation over an efficient, fluctuation-independent energy and heat storage up to the innovative, regenerative energy conversion by means of CHP, heat pump or PV-systems many different alternatives are realizable here (Umweltbundesamt 2017 p. 65).

The fact that at present the focus of energy-saving renovation efforts is often exclusively on energy savings is to be seen critically. Because in reality no actual energy shortage is the biggest environmental problem. Energy is more than enough available, the known oil reserves alone are five times larger than ever may be burned (Oehler 2017 p. 72); the situation is similar with gas reserves or solar and wind energy. The real climate problem is therefore not so much an energy problem as an emission problem: the danger for our environment and for the climate is posed on a large scale by increasing CO_2 emissions, which are not due to increasing energy consumption, but solely to the choice of energy sources. Because the use of oil, gas or wood always goes hand in hand with the emission of greenhouse gases, even with the most economical consumption, and separate CO_2 prices are also proving to be very effective. In the future, therefore, the only way forward will be a combustion-free energy supply with regenerative electricity, which in view of the climate targets up to 2050 will lead to increased electricity consumption in this period (Oehler 2017 p. 73 f.).

So even in Germany it is by no means enough to push for an energy turnaround as soon as possible by means of energy savings and to take the increasing share of energy generation from resource-conserving, regenerative sources as an opportunity to see the climate targets as already secured. Looking at the actual figures for national CO_2 emissions, it is noticeable that these rose from 12.0 to 12.3 tonnes per capita between 2000 and 2010 (Oehler 2017 p. 78). Research and new approaches in the field of emission-free and energy-efficient building standards are therefore still urgently needed (Oehler 2017 p. 95)

Accordingly, new political reports and documents are now even turning their attention beyond the individual buildings to entire neighbourhoods that are to be created as energy-efficient urban neighbourhoods (Bundesministerium für Verkehr, Bau und Stadtentwicklung 2009 p. 10) with the help of climate-friendly urban development (Bundesministerium für Verkehr, Bau und Stadtentwicklung 2011 p. 105). Against this background, the requirements of today's energy policy debates must be met by a special technical, regenerative energy supply system, strong savings in energy consumption, increased energy efficiency and energy-optimised building design (Sturm and Mattissek 2018 p. 113).

For every successful new configuration as well as for the functioning operation of a transformed energy system, it is also generally important to achieve not only acceptance and insight on the part of the property owners, but also low land consumption and, above all, maximum economic efficiency (Faller 2018 p. 237). Because in order to achieve the ambitious goal of climate neutrality in the building sector by 2050, contrary to the sobering trend currently emerging, the current renovation rate of around one percent urgently needs to be doubled, especially in the enormously large building stock from times before the Thermal Insulation and Energy Saving Ordinance (Hook 2018 p. 41). To this end, however, an energetic refurbishment measure must not only be sensible from an ecological point of view, but also from an economic point of view. In general, it can be assumed that energetic renovation measures for economical and rational energy use will ultimately only be carried out if they result in cost savings, even if other important requirements apply in the operational energy sector in addition to the purely economic objective (Leemann 1992 p. 1). The question of the specific economic efficiency of an energetic and technical rationalisation and renovation measure is therefore extremely central. It is therefore extremely important to assess this economic efficiency in advance of an energy system transformation by means of evaluation procedures such as the IRR, the LCOE or the EROI - all the more so since, especially in the case of energy, more than with other production factors, there is usually a flexibility of costs downwards. (Leemann 1992 p. 1).

In order to correctly assess the economic efficiency of a transformed building energy system, the service life of the respective system must also always be taken into account. In general, against the background of an ecological, sustainable, energetically and structurally resource-saving building stock, it is important to focus on the complete life cycle (Deutsche Umwelthilfe 2018) of a building and in the course of this "to achieve the greatest possible synergy effect at the lowest possible price in order to enable the building to live as long and healthy a life as possible (Oehler 2017 p. 71).

For this reason, it should be briefly stated at this point that the sole transformation of a building energy system is by no means enough in favour of an ecological, sustainable, energy-friendly construction sector. Buildings are generally characterised by a comparatively long service life, which is why plant operation and building use as well as the sustainable preservation and renovation of existing buildings are of such much greater importance than the mere construction of a new building itself; in view of the enormous flow of materials and energy during disposal, the end-of-life of a building with the construction waste it generates also plays an important role (Ekkerlein 2004 pp. 1, 3 f.).

However, in the context of building lifetimes of more than 100 years, the question often arises as to how reliable forecasts of energy raw material and electricity price developments or future technical (legal) requirements can be made at all, on the basis of which the decision on a long-term profitable energy system transformation could ultimately be made responsibly. Since it is by no means possible to make reliable estimates so far in advance, in particular of the economic viability and regulatory situation, it is in practice only possible to theoretically limit the period under consideration to 30 to 40 years. This is usually sufficient, since experience has shown that many of the cost-intensive, energy-intensive modernisations and renovations will be required for the first time around 30 years after completion of construction anyway (Pelzeter 2016 p. 60 f.).

How important it is to focus not only on the current building energy system, its current energy consumption figures and its (short-term) energy system transformation, but also to take into account the other effects of a building, in view of such long building lifetimes, is shown by the other environmental impacts of buildings. Apart from the energy consumed during the longest phase of a building - the operation of the building - the numerous materials used in the building, the resources used elsewhere and, last but not least, the sealed surfaces also have a wide range of effects on the climate and the environment (Ekkerlein 2004 p. 1, 3 f.).

Every climate-effective, emission-reducing energy system changeover therefore always requires a profitable interaction with other building blocks (such as land consumption) in order to optimise the entire life cycle assessment of a building. After the generation and use of energy in the context of the intended focus on climate objectives, land consumption in particular plays an almost equally central role here. Against this background, however, the unit of measurement energy consumption per m^2 building area commonly used in connection with greenhouse gas emissions is unfortunately not very meaningful, even misleading: Instead of emphasizing the ecological advantages of compact construction methods, this unit of measurement even disadvantages such compact buildings in exactly the opposite way, whereas all larger areas with the same number of users are virtually rewarded. It would therefore make more sense here to introduce the unit of measurement CO_2 per capita, i.e. to determine the emissions per inhabitant or workplace.

Like a carbon footprint, well utilised, compact buildings would perform better, since the per capita share of the total emissions generated by the building would automatically be lower than for a large apartment with very few residents or workplaces (Oehler 2017 p. 78).

To present the further connections, conditions and necessities in connection with the reduction of emissions, climate neutrality and the conversion of the energy system would go beyond the scope of this thesis. For further in-depth information, reference must be made here to further literature or reasearch.