CLIMATIC IMPACT OF RESIDENTIAL BUILDINGS

An Examination of Greenhouse Gas Emissions in the Residential Building Sector, Factors that influence Energy Use and the Energy Saving Potentials analysed for the Borough Altona in Hamburg

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“A safe, environmentally sound, and economically viable energy pathway that will sustain human progress into the distant future is clearly imperative. It is also possible. But it will require new dimensions of political will and institutional cooperation to achieve it.”

Quote from the report of the World Commission on Environment and Development “Our Common Future” in 1987

(UN, 1987, p. 21)

Abstract

Global warming is induced by rising greenhouse gas concentrations. In order to decrease concentrations, mitigation targets for the reduction of greenhouse gas emissions have been defined on global and local levels. The residential building sector represents a keyfield of action where mitigation measures can be implemented.

Regarding the life cycle of residential buildings in places like Hamburg, the emissions are highest during the operational phase. Emission investments of retrofitting measures are only amortised after a few years. In Germany, emissions deriving from space heating have the highest share of all operational emissions. The emission factor for applications based on electricity is much higher, but their share in final energy use is rather low.

In the case study of Altona, one of seven boroughs in Hamburg, energy use for electricity and heating in private households in the year 2015 was collected, allocated to Statistical Areas and geographically illustrated. Hamburg's target to limit heat energy use to a maximum of 55 kWh/m² by 2050 could be fulfilled in a small number of Statistical Areas. However, in a much larger share of Statistical Areas, energy use was around four times as high. Energy use and emissions per inhabitant tended to be rather low in urban areas and high in areas close to the river Elbe and in the suburbs. In nearly all areas of Altona, annual emissions per capita exceeded 1 t CO_2 with a large number of areas exceeding 2 t CO_2. The results emphasize an existing need for action in the residential building sector.

The following linear regression analyses have calculated existing correlations of variables regarding urbanization, inhabitants and residential buildings with electricity and heat energy use. The objective was to gain a better understanding of existing interdependencies and the possibility to adjust mitigation action. The results showed that in Altona, density and urbanization, low shares of single family houses and elderly people, as well as low shares in employment and unemployment can serve as indicators for low energy use. Overall, the strongest correlations existed with income and living area per person. Building age did not show any correlation with energy use.

The most effective measures of energy efficiency in the borough Altona would target living area per person and retrofits. Regarding carbon intensity, an increase in renewable sources is needed to improve the emission factor of district heat and electricity. Generally, the need and scope of measures could be determined more precisely if a monitoring system was introduced.

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I want to express gratitude to several people, who have helped and inspired me during my master program and thesis.

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List of Abbreviations

A/V ratio	Surface/volume ratio, meaning the ratio of an object's surface (A) to its volume (V)
ALKIS	Amtliches Liegenschaftskatasterinformationssystem
BSU	Behörde für Stadtentwicklung und Umwelt (in English: State Ministry for Urban Development and the Environment) (since 2015 split into BUE and BSW)
BSW	Behörde für Stadtentwicklung und Wohnen (in English: State Ministry for Urban Development and Housing)
BUE	Behörde für Umwelt und Energie (in English: State Ministry for the Environment and Energy)
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalents
COP23	Conference of the Parties (meaning parties of UNFCCC), Number 23
EnEV	Energieeinsparverordnung in English: Energy Saving Regulations
EPS	Expanded Polystyrene
ERF	Effective Radiative Forcing
EU	European Union
GABC	Global Alliance for Buildings and Construction
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GWP	Global Warming Potential
HmbKlischVO	Hamburger Klimaschutzverordnung (in English: Hamburger Climate Protection Regulation)
HP	Heat Pump
IEA	International Energy Agency

IFB Hamburg	Hamburgische Investitions- und Förderbank (in English: Hamburger investment and development bank)
IPCC	Intergovernmental Panel on Climate Change
IWU	Institut Wohnen und Umwelt (in English: Institute for Housing and Environment)
LAK	Länderarbeitskreis Energiebilanzen
NABU	Naturschutzbund Deutschland e.V. (in English: Nature Conservation Union Germany)
NIR	National Inventory Report
OECD	Organisation for Economic Co-operation and Development
PtJ	Projektträger Jülich
RCP	Representative Concentration Pathways
SDG	Sustainable Development Goal
UBA	Umweltbundesamt (in English: Federal Environment Agency of Germany)
UNFCCC	United Nations Framework Convention on Climate Change

Content

1 Introduction

On the 28th of March in 2018, the news claimed: Germany's annual CO_2 emission budget was already used up (Norddeutscher Rundfunk, 2018). Where does this budget come from and how come Germany was so far off target? News about climate change and climate protection can be found in the media, but sometimes the background information is vague so that the implications and necessary responses are not clear.

Where do the emissions occur? The Nature Conservation Union Germany (NABU) states that residential buildings hold a large share in total emissions. The amount of emissions is influenced by different factors, such as the living area and shape of buildings (2014).

When quantifying and allocating emissions, difficulties occur. When emissions are allocated to the place of occurrence, liability is placed on producers rather than on consumers. Trends in emissions can turn out very differently as it is the case in Hamburg (Tiedemann, 2015).

So how should local action in every individual sector be addressed in the context of the global issue of climate change? What is the role of the residential building sector specifically? How does a borough in the city of Hamburg tackle emission reductions? These questions and many more will be addressed in this paper.

1.1 A new Approach

To decrease global warming, emission reduction goals are set on several action levels starting globally, proceeding up to local levels (cf. chapter 2). These targets also exist at the level of cities. Hamburg for example aims at an 80 % reduction of all emissions by 2050 (cf. chapter 2.5.4). The question that remains mostly unanswered is: What amounts are allocated to each sector?

Regarding residential buildings, Hamburg defines an average amount of energy consumption per square metre that is to be achieved by 2050 (Bürgerschaft der FHH, 2015, p. 28). While there is a database for emission reductions of public buildings (ibid., p. 36), there is nothing alike for private, residential buildings. To quantify effects of individual measures, a bottom-up approach was developed (ibid., p. 73). However, it only allows an estimation of energy savings of certain actions, but does not give an overview of all existing emissions.

Even if average consumption and emissions were calculated for Hamburg, how should responsible authorities identify areas of high consumption and emissions? When new districts with energy concepts are developed, monitoring can be integrated in an easier way (such as HafenCity Hamburg GmbH, 2017, p. 23). However, the building stock is not monitored and therefore much harder to grasp.

Authorities such as Bezirksamt Altona, who represents and manages the borough Altona in Hamburg, are currently only provided with data at the city level or the level of individual buildings. Planners and policymakers do not have the data available defining areas of high and low energy use. This situation makes it challenging to assess current consumption and emissions, and therefore select effective measures for the future. Emissions would then need to be tracked “on a human scale” (Gurney, 2015).

This is why a new approach was developed in this paper. It works at the level of Statistical Areas, which is between the district level and the level of building blocks. It therefore facilitates a detailed overview of the borough while still complying with data protection. Its goal is to get a better understanding of current energy uses in residential buildings and the resulting emissions. Correlations are calculated to identify possibly influencing factors on energy use. This approach is expected to help an Authority such as Bezirksamt Altona to get a detailed picture of current energy uses, but also to maintain an overview of use at the same time. By gaining a better understanding of consumption and emission values, the aim is to have the ability to implement effective mitigation measures.

1.2 Assumption and Research Questions

To limit global warming, efforts are required in every sector. The residential building sector needs to contribute to existing mitigation targets. In order to do so, further research is needed.

Hypothesis

The residential building sector is one of the most important sectors to reduce greenhouse gas emissions, but current knowledge about its different influencing factors and an effective, meaningful scope of action on the local level has not yet been fully prepared. To gain a better idea of effective measures, the interdependencies of actual energy consumption and other characteristics need to be found.

Prediction

When correlations are quantified, the existing scope for manoeuvre will be better understood. Additional quantifications of greenhouse gas emissions will enable a transparent quantification of the effect on the climate. With both estimates, the fields of action with the greatest impact on greenhouse gas reduction will be apparent.

Research Questions

This paper is structured around six research questions. The summarized answers can be found in section 6.3.

1. What is the impact of the residential building sector on the climate?

2. Which area within the residential building sector has the largest impact on the climate?

3. Which characteristics influence the energy use in residential buildings in Altona?

4. What target of climate impact in the residential building sector should Altona reach for?

5. How can the district Authority reduce the impact on the climate of the residential building sector in Altona?

6. Is the approach of analysing energy consumption and other influences on the local level effective and practical for other municipalities?

1.3 Structure and Method of Research

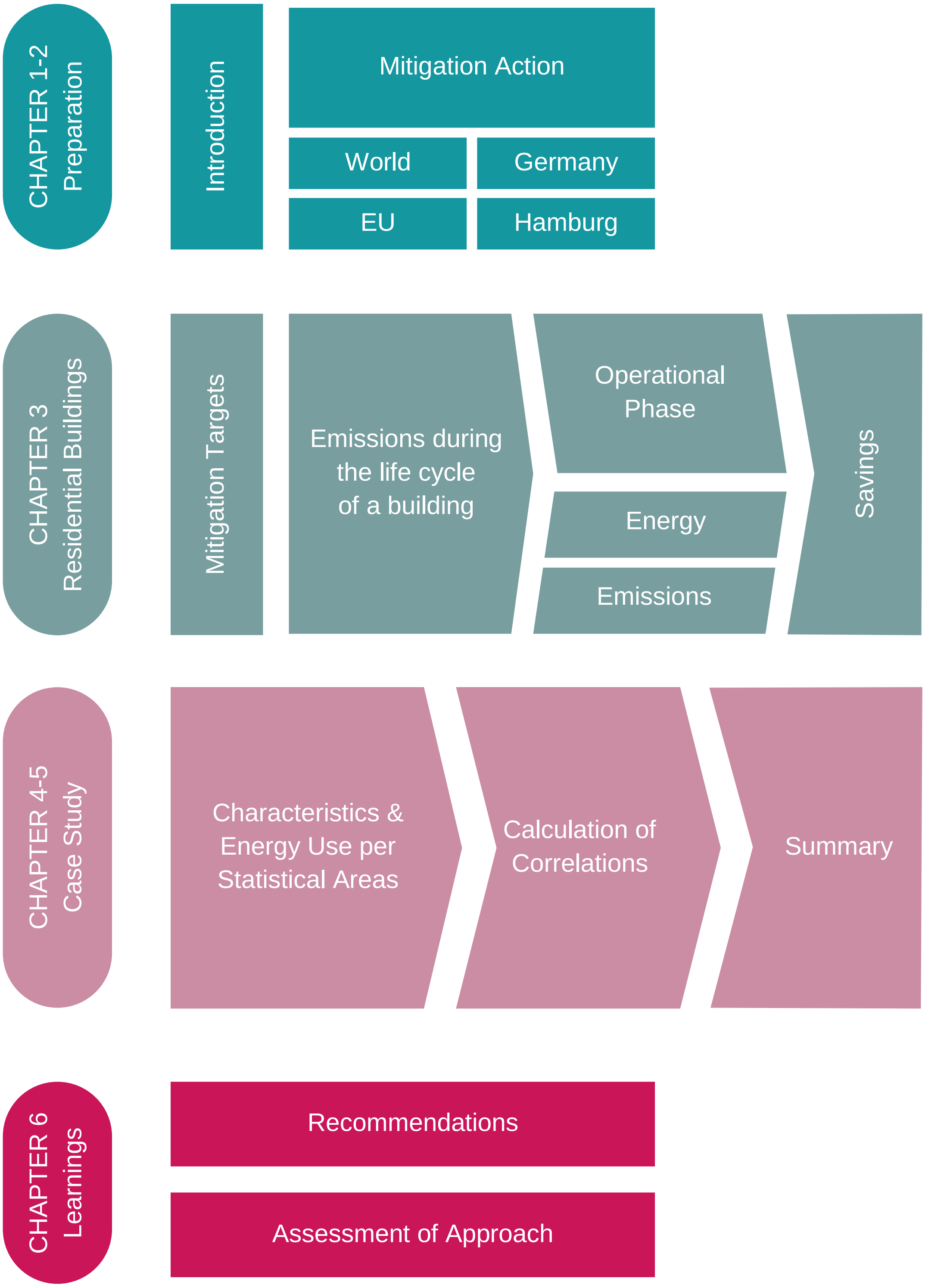
The decisive factor for this master thesis was the climate protection concept that was prepared in 2017 and 2018 for Altona, a borough in Hamburg. Existing climate protection concepts, such as that of the borough Bergedorf (Gottschick et al., 2016), contain strategies and measures, but usually do not set specific reduction goals and do not put in place monitoring tools. Since responsible authorities are able to operate over public buildings, private buildings are only touched by building regulations and retrofitting incentives. This paper can be seen as a trial to go into more detail than existing climate protection concepts and therefore open new doors for mitigation measures.

The thesis begins with the basics and describes climate change, latest trends and current mitigation action. This specification is necessary to understand the global issue of global warming, which needs to trickle down to local action. The analysis is based on the evaluation of the latest, existing literature and published data.

Chapter 3 then moves on to the residential building sector. Here, the current situation globally and locally is examined and anticipated targets on all these levels are shown. The analysis explains the importance of the residential building sector with regard to emission targets. To specify further, emission shares of different phases of a building’s life cycle are shown. The results lead to the focus on operational emissions only. Here, energy use and emission factors are presented, which reveal first insights on energy and emission saving measures. Again, literature and published data are used.

In chapter 4, the borough Altona is then profiled, illustrating several socio-demographic factors and energy uses in residential buildings. Using this as the base of data, correlations are calculated in chapter 5 with the help of the statistic programme ‘R’. The results lead to savings potentials and recommendations.

Finally, the approach is evaluated in a reflective assessment. Several experts were interviewed to get a more complete picture of the developed approach and its usefulness.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2 Mitigation Action

This chapter will start with basic information on climate change and illustrate different climate scenarios. As it will be shown, the scenarios depend mainly on GHG concentrations in the atmosphere, which are highly influenced by human action. Human kind can consequently control the future climate to a certain extent. Several parties have decided to do so actively and work towards a preferred scenario. These measures are referred to as “mitigation action” in this paper.

The chapter will first give an insight on emission accounting, which is necessary to understand how GHG emissions are calculated and to comprehend emission statistics. It then moves on to emission trendsand reduction goals worldwide, in the European Union, in Germany and in Hamburg. It ends up at the level of a municipality, with the aim is to understand climate action on a local level in the context of the global issue.

2.1 Global Warming and the Greenhouse Gas Effect

The term “climate change” describes a transformation of a climate, which existed for preceding decades (IPCC, 2014a, p. 120). To differentiate from climate variability, the term climate change can be defined as anthropogenic (UN, 1992, article 1), which is how it will be used in this paper. A change in climate, which has been recorded since the industrial revolution after 1750 and is expected in the future, is global warming. During the previous century the global average surface temperature has increased by more than 1°C, accelerating to an increase of nearly 0.3°C per decade since 1979 (Hartmann et al., 2013, p. 187). According to the Intergovernmental Panel on Climate Change (IPCC), more than half of the temperature increase from 1951 to 2010 was anthropogenic (2014, p. 48).

Rising temperatures are induced by the greenhouse effect. Greenhouse gases (GHG) partly block heat reflected by the earth, which leads to a temperature increase (Henckel et al., 2010, p. 258). This characteristic of GHG can be called “radiative forcing”. Therefore, the concentration of GHG in the atmosphere alone (cf. IPCC; 2013b, pp. 1401-1403) does not express the influence on climate change yet. Instead, the effect can be expressed in radiative forcing. Taking the year 1750 as ground zero, effective radiative forcing in 2011 was at 2.2 W/m² (IPCC, 2013b, p. 1409). CO_2 has the highest share in radiative forcing (ibid., p. 1409) and future scenarios project the share to increase (Van Vuuren et al., 2010, p. 24).

Besides radiative forcing, another unit used to indicate the impact of gases on global warming in a uniform way is CO_2 equivalents. The unit is written as CO_2e or CO_2eq. It is based on the Global Warming Potential (GWP) relative to CO_2 (cf. IPCC, 1996, p. 22) and converts the amount of a given gas to the amount of CO_2, which would show a similar effect on global warming (Destatis, 2017a, p. 93; IPCC, 2014a,

p. 121). The GWP of methane over a 100-year horizon for example is 25 times as high as that of CO_2 (UN, 2014, p. 24). A ton of methane therefore is equal to 25 tons of CO_2e, meaning a unit of methane contributes to the greenhouse effect 25 times as much as a unit of CO_2. The unit of CO_2e is commonly used in emission statistics and will also be used in this paper. From all recorded GHG emissions expressed in CO_2e, the share of CO_2 was 81 % in the EU (EEA, 2017, p. 72) and 88 % in Germany (UBA, 2017b, p. 70). When emission statistics refer to only CO_2, one should keep consequently in mind that while it does not include all GHG, this still covers the largest share of all GHG emissions.

In Germany CO_2 represents 88 % of all recorded GHG emissions.

2.2 Climate Scenarios

In its Fifths Assessment Report from 2013/2014, the IPCC has modelled four different scenarios, which indicate different ways of climate change until the year 2100. They are called "Representative Concentration Pathways" (RCP) and carry the approximate radiative forcing in 2100 of each projection in their names (IPCC, 2013a, p. 29).

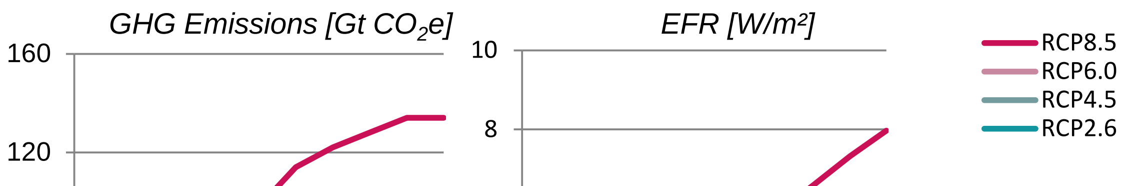

Figure 1: Annual Anthropogenic GHG Emissions (adapted from Meinhausen et al., 2010, p. 223) and Total Anthropogenic Effective Radiative Forcing (EFR) from 2000-2100 for the four different Scenarios (adapted from IPCC; 2013b, p. 1435)

As shown in Figure 1, radiative forcing in 2100 relative to 1750 is expected to be somewhere in between 2 W/m² and 8 W/m². These values are the result of different scenarios in anthropogenic GHG emissions. The scenario RCP2.6 is a projection of GHG mitigation, RCP4.5 and RCP6.0 of stabilization and RCP8.5 one of very high emissions (ibid., p. 29)[I]. Driving forces for each scenario are different projections of population growth, GDP, energy consumption and energy mix (Van Vuuren et al., 2010, pp. 16-18). The scenarios are

[I] For projections until 2300 drastic emission reductions are expected for RCP6.0 and RCP 8.5 (Meinshausen et al., 2010, p. 228). However this paper will mainly focus on the period until the year 2100.

supposed to represent "a range of 21st century climate policies" (IPCC, 2013a, p. 29).

The different projections of radiative forcing lead to different projection of global warming. Relative to the mean from 1850-1990, the global surface air temperature had risen by 0.6 °C in 1968-2005 already (IPCC, 2013b, p. 1444). The projected additional increase of global mean surface temperature in 2090 ranges from 1°C to 3.5°C relative to the year 2000 (cf. Figure 2). In comparison with pre-industrial levels, this represents an increase of 1.6°C to 4.1°C (IPCC, 2014b, p. 13).

The scenarios project sea level rises of 44 cm to 74 cm in 2100 (cf. Figure 2). Additionally, the contrast in wet and dry seasons and regions will increase, the ocean will continue to warm and global glacier volume will decrease (IPCC, 2013a, pp. 20, 24). These changes have led to impacts on the wellbeing of humans and ecosystems. Further changes will lead to further impacts.

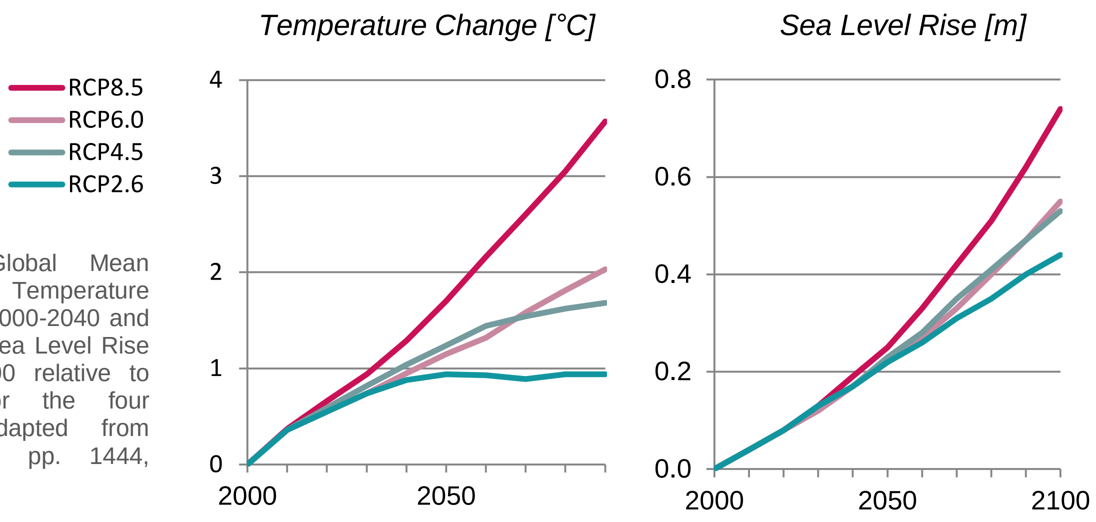

Figure 2: Global Mean Surface Temperature Change from 2000-2040 and Global Mean Sea Level Rise from 2000-2100 relative to 1986-2005 for the four Scenarios (adapted from IPCC, 2013b, pp. 1444, 1445)

2.3 Mitigation Targets

In order to reduce the GHG effect, the amount of GHG in the atmosphere needs to be reduced. This can be achieved by fostering sinks on the one hand and reducing greenhouse gas emissions on the other hand. Both areas of activity are called mitigation of climate change as opposed to the term adaptation, which refers to measures of adjusting to changing conditions (IPCC, 2014a, pp. 118, 125). This paper will focus on mitigation measures in terms of GHG emission reduction only.

Targets are set on several levels, so that aspired reductions are quantified. Generally, targets have the purpose to “regulate action towards goal achievement” (Björnberg, 2013, p. 286). Their achievement should be evaluable and reachable by actions. Also, the goal needs to be formulated clearly and to have the capacity to motivate (ibid., p. 286).

Mitigation goals can be set for every step of the cause-effect chain (cf. Figure 3) and consequently either address the issue of emissions, atmospheric concentrations, temperature or impacts. Depending on the addressed issue, every target has certain characteristics. Temperature targets for example are highly understandable, but are only distantly linked to emissions as drivers, while concentration targets are rather unfamiliar and emission targets are distant to impacts (ibid., p. 291).

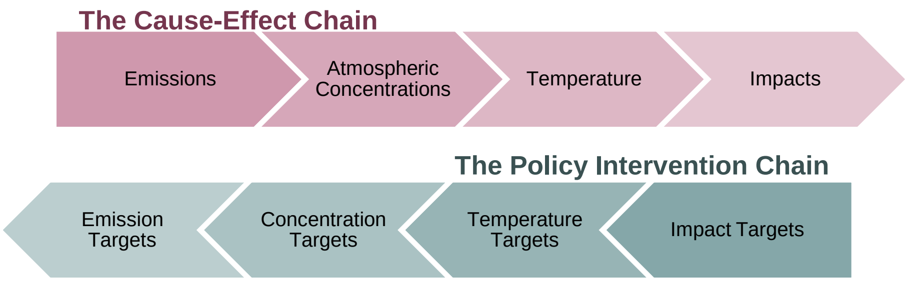

Figure 3: The Cause-Effect Chain and the Policy Intervention Chain (adapted from Björnberg, 2013, p. 287)

As shown in the following sections, mitigation action today is led by a temperature target. This target is then broken down to emission targets on several levels. This paper will name existing targets and evaluate their achievability, but will not question their installation.

2.4 Emission Accounting

To understand and evaluate GHG emission reduction, emissions need to be quantified regularly. There are two methods for accounting: production-based (in German: Quellenbilanz) and consumption-based accounting (in German: Verursacherbilanz).

Production-based accounting assigns emissions to the place of occurrence, even if produced goods are exported elsewhere. Consumption-based accounting assigns emissions to the place of demand, and therefore includes so-called embodied emissions of imported goods. These embodied emissions include all emissions during the phases of production, transportation and sale (Boitier, 2012, p. 2; Peters & Hertwich, 2008, p. 1403).

Globally, one fifth of emissions are traded (Afionis et al., 2017, p. 2; Jakob et al., 2013, p. 6). Developed countries tend to have higher CO_2 imports than exports and are therefore CO_2 consumers, while developing countries are mostly CO_2 producers (Boitier, 2012, p. 11; Jakob et al., 2013, p. 6). In developed countries consumption-based emissions are consequently higher than production-based emissions, while in developed countries it is the other way round. Germany for example imported 141 Mt CO_2 more in 2009 than it exported (Fan et al., 2017, p. 3503), meaning that its consumption-based CO_2 accounting was 18 % higher than its production-based accounting (cf. UBA, 2017b, p. 69).

The UN demands annual “national inventory of anthropogenic emissions” (UN, 1992, p. 23) in so-called National Inventory Reports (NIR). They only include emissions “taking place within national territory” (Rypdal et al., 2006, p. 1.4), which implies production-based accounting. The responsibility for emission is therefore assigned to the producer instead of the consumer (Jakob et al., 2013, p. 2). Discussions about GHG reduction refer to “emissions at the point of production” (Afionis et al., 2017, p. 2).

In global and national statistics GHG statistics are mostly calculated according to the production-based approach. On more local levels, the consumption-based approach is used to express the effect of local action. There are several advantages and disadvantages for every approach. Carbon leakage for example is a characteristic of production-based accounting. It implies the effect of increasing emissions in a region due to reductions in another region (Jakob, 2013, p. 2; Michalek & Schwarze, 2015, p. 1472)[i]. While this paper will not evaluate chosen approaches (such as done by Afionis et al., 2017), the differentiation of the two should be kept in mind.

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[i] It was estimated that in 2001 mitigation policies in Germany have caused 13.7 % of its production-based emissions in places with less restrictions (Peters & Hertwich, 2008, p. 1404)

2.5 Mitigation Targets on different Levels

2.5.1 Globally

The first step towards global climate action was made in 1987 when the World Commission on Environment and development published the report “Our Common Future”. In 1992, 197 countries signed the United Nations Framework Convention on Climate Change (UNFCCC). The main aim was to “achieve […] stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (UN, 1992, p. 9). The 43 parties including the European Union (EU) listed in Annex I of the Convention (ibid., p. 32) have to submit their GHG inventories annually (ibid., p. 10).). In1997 legally binding limits of GHG emissions[I] were set by the Kyoto Protocol for every country. It entered into force another eight years later.

Figure 4: Logo of the UN (Author, 2017)

The development of global GHG emissions from 1990 to 2010 is shown in Figure 5[II]. All countries with a share in global emissions of more than 2 % are named individually, while all others are compiled in groups. Annex I countries are the 28 member states of the European Union (EU), Canada, Japan, Russia, the USA and 11 other countries. They keep track of their GHG emissions, which are published by the UN (n.d., a). Germany is included in the group of EU countries. Absolute emissions of all Annex I countries have slightly decreased since 1990.

As recorded by The World Bank (2018a) China shows the largest increase in emissions. It nearly tripled its emissions from 1990 to 2010, reaching a share of 22 % in global emissions in 2010. India and Brazil have also doubled their emissions from 1990 to 2010. The top part of the columns in Figure 5 presents the other 149 countries in the world. They represent a third of global emission and their trend is to increase[III].

Today’s most important climate goal was established in the Paris Agreement 2015, which replaced the Kyoto Protocol. It entered into force in 2016 and by January 2018 it was ratified by 174 parties (UN, n.d. b). Its main goal is a limitation of global warming to 2°C relative to pre-industrial levels, aiming for a limit of 1.5°C (UN, 2015a, p. 3). Regarding the RCP scenarios, this decision means that the parties

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[I] Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur Hexafluoride (SF_6) (UN, 1998, p. 19)

[II] A comparison with the latest GHG inventory report of the EU (EEA, 2017) indicates that international aviation and maritime transport are not included in the data. Total anthropogenic emissions would consequently be higher than presented.

[III] Estimates for the year 2015 are not available yet, but can be expected to be published by the World Bank by the end of 2018.

therefore strive to achieve the most ambitious scenario (cf. section 2.2). All parties are supposed to reduce GHG emissions as soon as possible (ibid., p. 4) and to enhance sinks (ibid., p. 6). But in contrast to previous agreements no emission limitations are set. Instead, countries hand in their Intended Nationally Determined Contributions (INDCs) themselves every five years (ibid., p. 5).

Current INDCs reduce annual global emissions insufficiently. Relative to emissions in 1990, emissions per capita are projected to decline by 10 % in 2030, but due to a growing population the total of global emissions would still be 44 % higher (UN, 2016, p. 10). Global emissions would therefore continue to increase (cf. Figure 5). This would lead to a temperature increase of more than 3.5°C by 2100 and 6°C by 2200 (Rose et al., 2017, p. 261).

In order to limit global warming, certain budgets of cumulative greenhouse gas emissions must not be exceeded. These budgets were calculated for the time since 1870 by the IPCC (2014a, p. 64). The more gases are emitted now, the smaller the budget in the future. The remaining budget can be spread evenly over the upcoming years, leading to the same limit in emissions every year. This had happened in the study, which the news report in the introduction (cf. chapter 1) was based on. In a more realistic way, emissions will not decrease abruptly and stay even, but decrease constantly. The UN has included this constant decline in their projection. To reach the goal of limiting global warming to 2°C, annual emissions in 2030 could be maximally 10 % higher than 1990 (UN, 2016, pp. 43, 48), while the 1.5°C goal requires to stay 12 % below emissions in 1990 (ibid., 2016, pp. 43, 53). The peak, meaning when annual global emissions start to decrease, needs to happen within the next years (UN, 2016, p. 12; Walsh et al., 2017, p. 7). A delay implies greater efforts in the following centuries (UN, 2016, p. 13), such as negative emissions (Rose et al., 2017, p. 259).

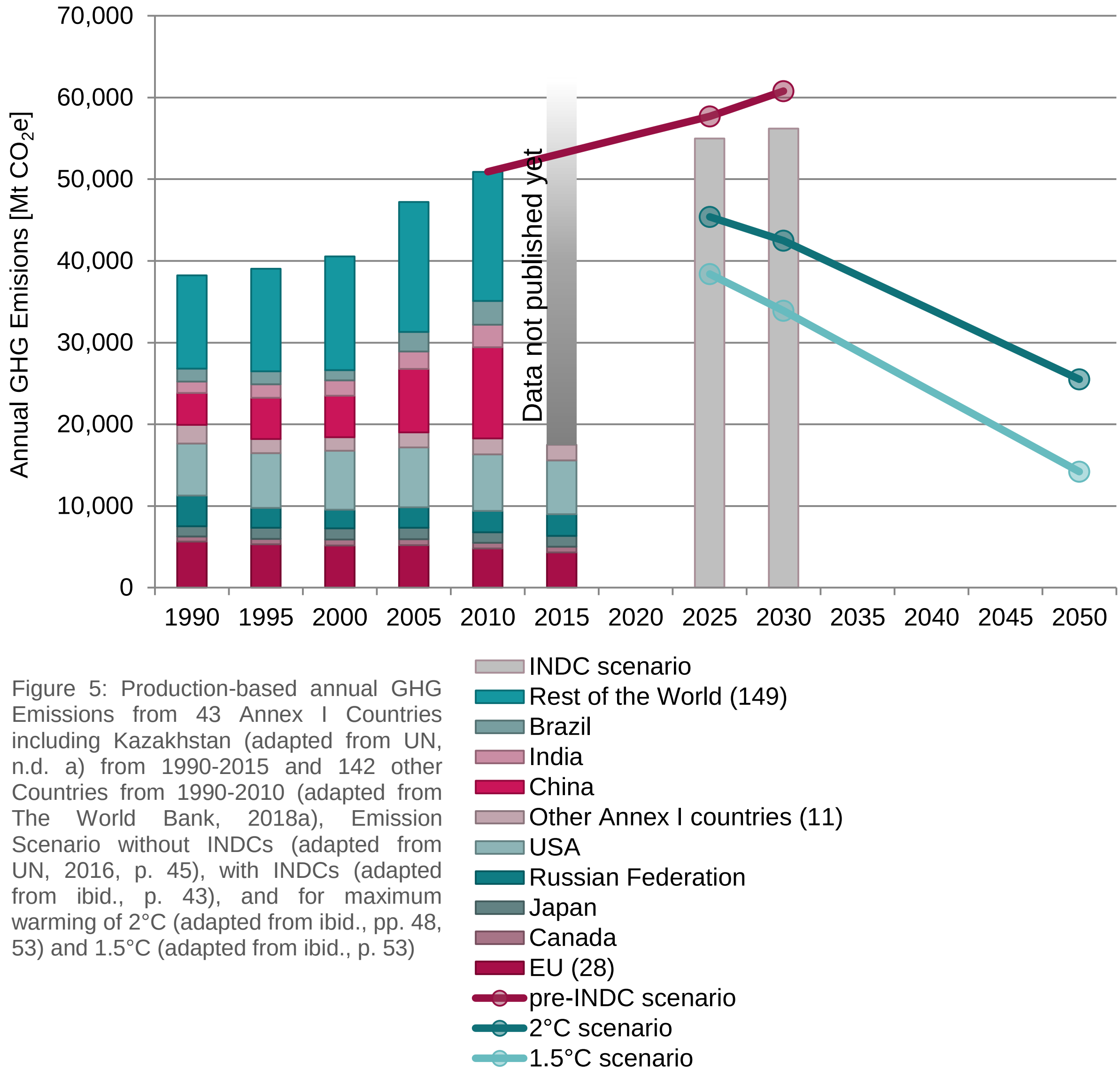

Figure 5: Production-based annual GHG Emissions from 43 Annex I Countries including Kazakhstan (adapted from UN, n.d. a) from 1990-2015 and 142 other Countries from 1990-2010 (adapted from The World Bank, 2018a), Emission Scenario without INDCs (adapted from UN, 2016, p. 45), with INDCs (adapted from ibid., p. 43), and for maximum warming of 2°C (adapted from ibid., pp. 48, 53) and 1.5°C (adapted from ibid., p. 53)

To make current performances of countries in climate action more accessible, different websites offer an overview and rate the performances. To name two of these websites, a coalition of different institutes for example publishes the "Climate Action Tracker"[I], while the association "Germanwatch e.V." created the "Climate Change Performance Index"[II].

[I] available at https://climateactiontracker.org/

[II] available at https://www.climate-change-performance-index.org/

2.5.2 In the EU

Figure 6: Logo of the EU (Author, 2017)

The European Union (EU) consists of 28 member states. All member states are members of the UNFCCC individually, as well as the EU itself. The EU defines greenhouse gas emission goals for the entity of all its member states.

As Annex I party the EU is obliged to submit its GHG inventories every year. The EU includes emissions from Iceland (EEA, 2017), leading to a total number of 29 countries. As predefined by the guidelines for GHG inventories, international aviation and maritime transport are generally not included (Rypdal et al., 2006, p. 1.5)[I].

In all inventories, emissions are categorised in different sectors: Energy, Industrial Processes and Product Use and Agriculture (Rypdal et al., 2006, p. 1.5). Sinks from the sector Forestry and Other Land Use and Waste are also recorded, but not presented in this paper.

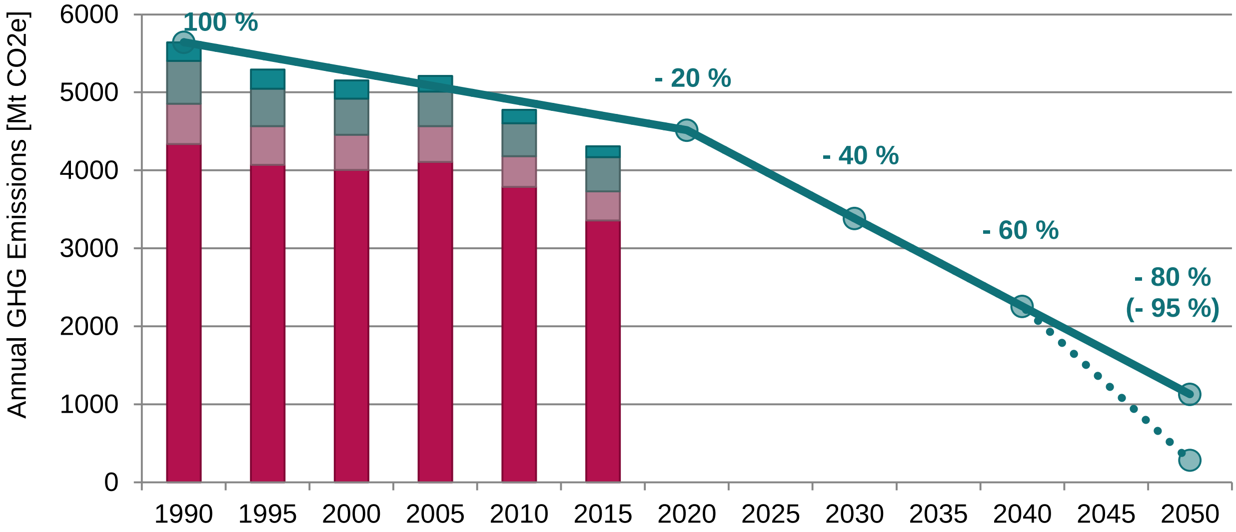

Figure 7: Production-based annual GHG emissions in the EU and Iceland from 1990-2015 (adapted from EEA, 2017, p. 80) and Reduction Goals from 2020-2050 (adapted from UN, 2015c, p. 845)

Figure 7 shows the development of GHG emissions of the EU and Iceland in these categories. The energy sector has a share of nearly 80 % in all emissions and has consequently the largest impact. Overall, the trend is a constant decline of GHG emissions.

[I] "In 2015 international aviation accounted for 143 Mt CO_2e and international shipping for 135 Mt CO_2e." (EEA, 2017, p. xii) This represents an additional 6 % of total GHG emissions in the EU, which are not included in the statistics.

Reduction goals of the EU can also be seen in Figure 7[I]. The goal of 40 % reduction by 2030 has been submitted as INDC (Latvian Presidency of the Council of the EU, 2015, p. 1). To reach the goal of 2020, the so-called effort sharing decision (ESD) was put in place (Decision No 406/2009/EC), which distributed the burden of emission reduction unevenly among its member states, taking into account their economic situation. The exact functioning and implications of this decision will not be discussed in this paper. The European goal for 2050 of a reduction of 80 % or more is absolutely needed for any scenario of global warming to stay below 5°C (Rose et al., 2016, pp. 258, 261) and could even be more ambitious (CAT, 2017).

2.5.3 In Germany

The results of the German GHG inventories from 1990 to 2015 are shown in Figure 9[II]. Considering European inventories, emissions in Germany represent around a fifth of emissions from the EU, which is the largest share of all European countries. Again, the energy sector has the highest share. Just as in Europe, the overall trend is a constant decline of emissions. However, since the reduction goal for 2020 is at 40 % instead of 20 %, the decrease needs to be stronger in order to achieve this upcoming goal. Current trends are not strong enough, so it is likely the 2020 goal will not be achieved.

Figure 8: Federal Eagle of Germany (Author, 2017)

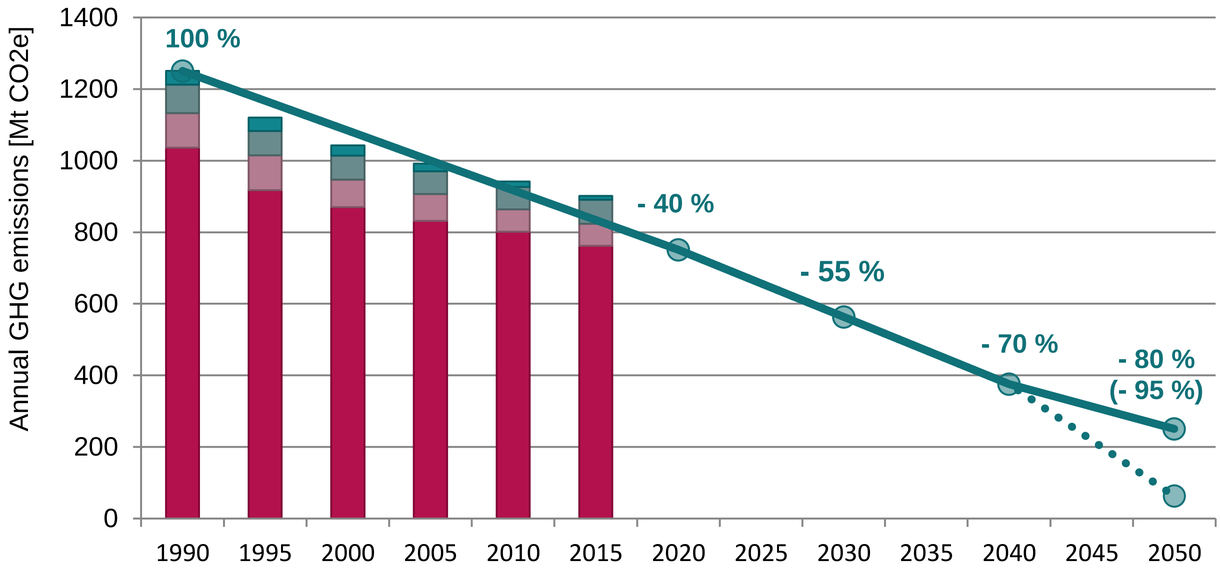

Figure 9: Production-based annual GHG Emissions and Sinks in Germany from 1990-2015 (adapted from UBA, 2017b, p. 69) and Reduction Goals from 2020-2050 (adapted from Deutsche Bundesregierung, 2010, p. 2)

[I] Uncertainties arise due to flexibility in the way the sector of land-use change and forestry is included (CAT, 2017).

[II] International air transport with nearly 25 Mt CO_2e in 2015 (UBA, 2017b, p. 160), international maritime navigation with 7 Mt CO2e (ibid., p. 162) are excluded in the inventory (ibid., pp. 159, 161). They would account for an additional 3.5 % in total GHG emissions.

2.5.4 In Hamburg

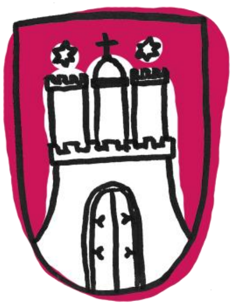

Figure 10: Hamburg's Coat of Arms (Author, 2017)

Hamburg is one of Germany's 16 states with a special characteristic as a city state. It was the first of all states to introduce a Climate Protection Act in 1997 (HmbKliSchG). However, GHG emission reductions today are much lower than the national average.

Comparability with national emissions is impeded by the change from production-based to consumption-based accounting. The development of consumption-based emissions from 1990 to 2015 can be seen in Figure 11[I]. Data has not been collected for the years 1998 to 2002[II], which is why there is a gap in the year 2000. The graphic only presents emissions from the energy sector, which on a national level was approximately 85 % of all emissions (cf. Figure 9). In addition, instead of quantifying all GHG emissions, in Hamburg only CO_2 emissions are tracked. On a national level, CO_2 represented 88 % of all counted GHG (cf. section 2.1). With these two constraints in mind, one can estimate the total GHG emissions for Hamburg to be approximately 35 % higher than the registered ones[III].

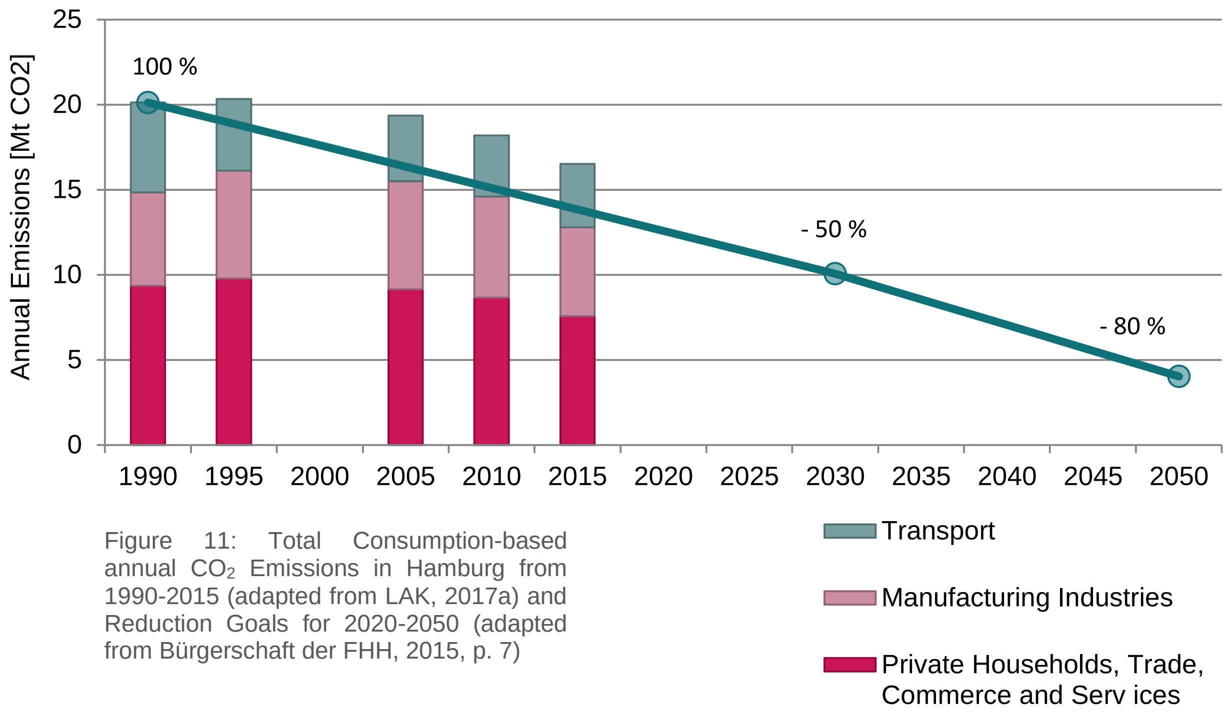

Figure 11: Total Consumption-based annual CO_2 Emissions in Hamburg from 1990-2015 (adapted from LAK, 2017a) and Reduction Goals for 2020-2050 (adapted from Bürgerschaft der FHH, 2015, p. 7)

[I] International Aviation is excluded. It accounted for an additional 4.5 % of total CO_2 emissions in 2015 (comparison between LAK, 2017a and LAK, 2017c).

[II] Confirmed by Dr. Hendrik Tietje (Statistikamt Nord) and Stephan Seiler (BUE Hamburg) during a telephone call on 17.01.2018

[III] To count back from 88 % to 100 % the factor is 1.14, while the factor for a conversion from 85 % to 100 % is 1.18, leading to a total factor of 1.35 (=1.14*1.18), which is an additional 35 %.

In the case of Hamburg the differentiation between production- and consumption-based emission accounting is of high importance. The reason for this is the fact that the coal-fired power station Moorburg was put into operation in the beginning of 2015 (BUE, n.d). The trial operation had started in 2014 already (Seiler, 2018). Production-based emissions have consequently risen noticeably since 2014. In 2015 they were 21 % higher than in the base year of 1990 (LAK, 2017b; cf. Figure 12), showing a converse trend considering emission reduction targets.

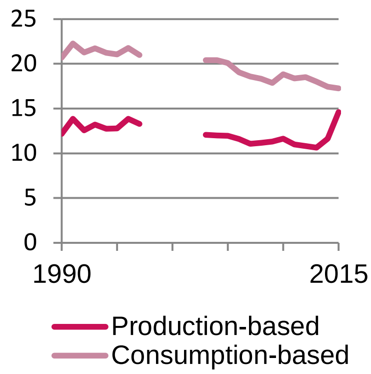

Figure 12: Annual CO_2 Emission [Mt] in Hamburg expressed in Production-based and Consumption-based Accounting Models (adapted from LAK Energiebilanzen, 2017a & 2017b)

Presumably this is the reason why in contrast to targets set by the EU and Germany, Hamburg's targets for 2030 and 2050 refer to consumption-based emissions (Seiler, 2018). However, as Figure 11 shows, even with this approach of accounting, reduction trends in Hamburg need to intensify to achieve the targets.

Hamburg's targets themselves are approximately in line with national targets. They aim for a long-term reduction of 80 % in 2050 (cf. Figure 11). However, the goal of a 40 % reduction by 2020, which was included in previous climate plans (Bürgerschaft der FHH, 2013, p. 2) and part of the reason why the city was elected as European Green Capital in 2011 (EC, 2011a, p. 14), has been excluded from the current climate plan (Bürgerschaft der FHH, 2015, p. 7). Instead, the amount of pursued CO_2 emission reductions in 2020 is expressed in an absolute number of two million tons (ibid., p. 7), which is the result of various interventions (ibid., pp. 88-90). The amount is quantified by a complementing bottom-up approach for emission accounting (Bürgerschaft der FHH, 2015, p. 73; Schüle et al., 2013). The next top-down target is that of a 50 % reduction by 2030. If emissions were reduced linearly, this would imply a decrease of 12.5 % every 10 years, implying a decrease of over 30 % by 2015.

The targets serve as informal framework, with which mitigation action can be aligned. In a political environment, the goals can be helpful to form alliances and to raise financial resources, but they are not legally binding (von Storch et al., 2017, p. 272).

2.5.5 The Perspective of a Municipality

Looking back from the level of Hamburg to the global challenge of GHG emission reduction, the impact seems very small. In 2010 Hamburg has emitted 12 Mt CO_2 in the energy sector (production-based approach) (LAK, 2017b), and presumably 16 Mt of GHG in total[I]. This was 1.70 % of all emissions in Germany[II], 0.34 % of those in the EU[III] and 0.03 % of all GHG emissions worldwide[IV]. Evidently, any attempt to quantify the global effect of emission saving of local measures is doomed to failure.

The reason why climate action should still take place on a local level is conscientiousness. Mitigation consists of various individual actions, which only have an impact at large. Hamburg has shown that it accepts its responsibility and addresses the issue of emission saving since the Climate Protection Concept from 2007 (Bürgerschaft der FHH, 2007, p. 1).

Noticeably, responsibilities are not split evenly. To reach the target of limiting global warming to 2°C, global GHG emissions would have to decrease to 33 % by 2050 relative to 1990. For the 1.5°C goal, a reduction of 63 % is needed (cf. Figure 5). However, the EU, Germany and Hamburg aim for an 80 % reduction (cf. sections 2.5.2, 2.5.3 and 2.5.4). What might seem kind and sacrificial looks self-evident and necessary when emissions are expressed per person.

Greater efforts of proportional emission savings can be justified by a greater culpability.

On a global average, GHG emissions per capita were 7.3 t in 2010 with only little variances in the years since 1990. This means that even though global emissions increased constantly (cf. Figure 5), population grew at approximately the same rate. Hamburg, the EU and notably Germany have emitted up to twice as much GHG per capita in the past centuries. When understanding equitable emission sharing relative to the population, certain parties have a greater accountability for GHG concentrations in the atmosphere today than others. Hamburg on a local level, Germany on an international level and the EU on a global level as polluters are more culpable than other parties on the same levels. This justifies greater efforts of proportional emission savings.

To reach the 2°C goal, emissions need to decline to 2.6 t per capita in 2050 (cf. Figure 13). This estimate is based on a population projection of 9.7 billion people in 2050 (UN, 2017). Due to uncertainties included in this projection, the expression of anticipated emission per capita needs to be considered with caution. The combination of absolute emissions as shown in Figure 5 and emission per capita provides the most comprehensive picture.

[I] 12 Mt CO_2 * 1.40 (cf. section 2.5.4) = 16 Mt CO_2e

[II] 16 Mt CO_2e / 942 Mt CO_2e (cf. Figure 9) = 0.0170

[III] 16 Mt CO_2e / 4,775 Mt CO_2e (cf. Figure 7) = 0.0034

[IV] 16 Mt CO_2e / 50,911 Mt CO_2e (cf. Figure 5) = 0.0003

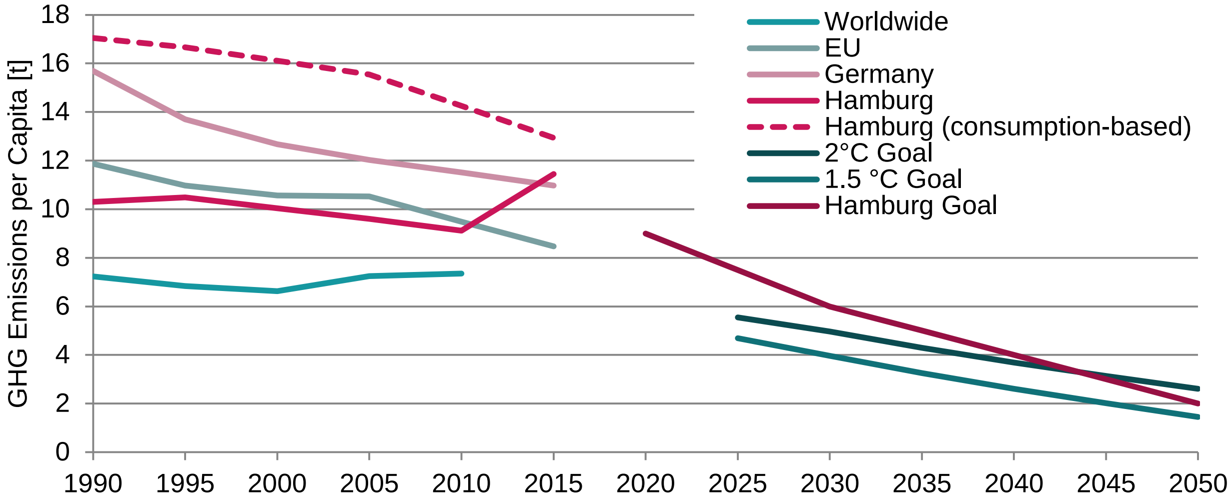

Figure 13: Annual Production-based GHG Emissions per Capita in Intervalls of 5 Years from 1990-2015 Worldwide (adapted from UN, n.d. a and The World Bank, 2018a with Population Data from The World Bank, 2018b) in the EU and Iceland (adapted from EEA, 2017, p. 80 with population data from Eurostat, 2018), in Germany (adapted from UBA, 2017b, p. 69 with population data from Destatis, n.d.), in Hamburg (adapted from LAK, 2017a and 2017b with Population Data from Statistikamt Nord, 2017), for the 2°C and 1.5°C Goal from 2025-2050 (adapted from UN, 2016, pp. 48, 53 with Population Projection from UN, 2017) and for Hamburg's Goal (adapted from Bürgerschaft der FHH, 2015)

Hamburg's targets for future emissions per capita are still rather high for the upcoming years, but in line with the 2°C goal in 2050 (cf. Figure 13). It should be noted that in Hamburg's current climate plan from 2015 estimates emissions at 10.2 tons per capita (Bürgerschaft der FHH, 2015, pp. 7, 77), which is less than data given above. Nevertheless, major effort and contribution from all sectors is needed to facilitate the achievement of Hamburg's emission reduction goals. This is the reason why the potential of emission savings in the residential building sector will be looked at in more detail.

3 Mitigation in the Residential Building Sector

After looking at general mitigation goals, the focus will now shift to the residential buildings sector specifically. The share of residential emissions, out of total emissions, will be identified for the different levels from global to local. The objective is to create a better understanding of the meaning of residential buildings with regards to GHG emissions.

Subsequently, emissions of different phases over the lifecycle of residential buildings are examined, leading to a focus on the operational phase. Here, energy use and resulting emissions are analysed in detail. Finally, the main emission saving strategies are presented.

3.1 The Residential Building Sector on different Levels

Similar to the recent approach to general mitigation, this chapter will lead from the global to the local level and show existing GHG emissions in the residential building sector.

First, it is necessary to define the term of "direct" and "indirect" emissions, so that an understanding of how emissions are assigned to the residential building sector is created. Indirect emissions occur in a sector different to that of the end user, but are assigned to the end-use sector (Verbruggen, 2007, p. 814). Indirect emissions of buildings for example can refer to electricity or heat generation, which take place in the energy sector. Even though they occur in the energy sector, they are attributed to buildings (ibid., p. 814; IPCC, 2014c, p. 678). To get the full picture of the impact of the residential building sector, indirect emissions need to be included.

This chapter will give an insight on GHG emissions taking place in the residential building sector and existing mitigation targets.

3.1.1 Globally

What is the share of the residential building sector in global emissions? When indirect emissions are included, residential buildings have emitted a total of 5.7 Gt CO_2e in 2010 (IPCC, 2014c, p. 678), which was 11 % of all GHG emissions[I]. It is composed of 4 % direct and 7 % for indirect emissions (cf. IPCC, 2014c, p. 678[II]). The estimate does not include emissions caused by construction, which for the entire building sector is approximately as high as indirect emissions of residential buildings (Abergel et al., 2017, p. 14). In the

Figure 14: Illustration of Residential Buildings with Logo of the UN (Author, 2018)

[I] 5.7 Gt CO_2e / 50.9 Gt CO_2e (cf. section 2.5.1) = 0.11

[II] Direct emissions: 2.2 Gt CO_2e / 50.9 Gt CO_2e = 4 %; indirect emissions: 3.5 Gt CO_2e / 50.9 Gt CO_2e = 7 %

past years, emissions from construction have increased, while carbon intensity of power generation has decreased (ibid., pp. 7, 14).

A global strategy for mitigation action in the residential building sector is difficult to determine. In the Sustainable Development Goals (SDGs), defined by the UN in 2015, the reduction of the adverse per capita environmental impact of cities is mentioned, as well as the intended increase in the share of renewable energy sources and the rate of energy efficiency (UN, 2015b, pp. 19, 21-22). However, special attention is directed at developing countries and their need to have a shelter and access to electricity in the first place. Indisputably, challenges within the building sector differ depending on the location. In places such as Africa and Asia, where a large share of buildings is yet to be built, the focus needs to be on new standards and building codes. In other countries, such as the Organisation for Economic Co-operation and Development (OECD) countries with Germany among them, more than half of the projected buildings stock of 2060 is already built. When most of the future building stock is already in place, energy renovations are of high importance (Abergel et al., 2017, pp. 7, 13). Challenges consequently vary in different parts of the world (cf. Appendix R).

The residential building sector accounted for 11 % of all global GHG emissions (direct and indirect).

Because of the large range of challenges, recommendations for emission reduction at the global level have been rather vague. At a global scale, the rate of energy renovations needs to rise from 1 % - 2 % to 2 % - 3 % (Abergel et al., 2017, p. 41). Besides retrofits of existing buildings, the IPCC points out two other major mitigation measures. The first one concerns the reduction of GHG emissions intensity through for example fuel switching. The second one is behaviour change to reduce energy demand (IPCC, 2014a, pp.103-104).

The main mitigation measures target retrofits, fuel switching and behaviour change

When looking at the quality of a building, energy standards can be set. Generally, the term “sustainable building” is commonly being used and needs to be defined more clearly (Andreas Hermling from Ecofys, Appendix R). Targets of sustainable buildings can for example define the limit of energy use per living area. According to the Global Alliance for Buildings and Construction (GABC), global final energy use needs to be reduced from 150 kWh/m² in 2015 to 100 kWh/m² in 2030 to meet goals set in the Paris Agreement. The estimate takes into account the global growth of floor area (Abergel et al., 2017, pp. 6-7).

Globally, the final energy use of buildings needs to be reduced from 150 kWh/m² in 2015 to 100 kWh/m².

The residential building sector has a strong potential for emission savings. The IEA estimates that if all countries followed the strategy of low-carbon and energy-efficient buildings, 4,900 Mt CO_2 could be saved annually (Abergel et al., 2017, p. 9). To reach the 2°C goal, the building sector needs to decarbonise and reduce emissions by 85 % relative to 1990. This can be reached by low-carbon power generation and energy-efficiency measures (ibid., p. 20). Roadmaps to achieve carbon-neutral buildings have been developed, for example by the non-profit organization "Architecture 2030" and the World Green Building Council. Due to scope limitations, they will not be discussed in this paper.

However, as Brian Dean from the International Energy Agency (IEA) put it, "the building sector is currently not on track to achieve a two degree scenario" (cf. Appendix R). So far, efficiency efforts have been insufficient to "offset strong growth in energy demand from rising population, floor area and buildings sector activity" (Abergel et al., 2017, p. 15). "Current trends indicate the potential for massive increases in energy demand and associated emissions." (IPCC, 2014c, p. 677) According to Brian Dean, energy use therefore continues to increase (cf. Appendix R).

3.1.2 In the EU

Figure 15: Illustration of Residential Buildings with Logo of the EU (Author, 2018)

Direct emissions in the European residential sector have decreased by a quarter from 1990 to 2015. However, because of the general emission decrease (cf. section 2.5.2), the share of residential emissions has constantly been between 9 % and 10 % (EC, 2017, p. 161), while globally the share of direct emissions deriving from the residential building sector was only 4 % (cf. section 3.1.1). Indirect emissions of the residential building sector were not reported. If they were included, the share of emissions originating in the residential sector would be even higher.

In the EU a renovation rate of 5 % is needed.

Several measures were put in place to reduce GHG emissions in the building sector in the EU and to address energy efficiency as well as energy supply. In regards to energy supply, renewable energy sources are promoted (Directive 2009/28/EC). To improve energy performance, all member states have to set energy efficiency standards for new and renovated buildings (Directive 2010/31/EU) and ensure that after 2020 all new buildings will be nearly zero-energy buildings (Directive 2010/31/EU). Retrofits are pushed by a renovation rate for public buildings and the obligation for every country to develop a renovation strategy (Directive 2012/27/EU). In order to reach the 1.5°C goal, a renovation rate of 5 % is needed (CAT, 2017). The long-term goal for 2050 is a reduction of emissions in the residential sector of approximately 90 % relative to 1990 (EC, 2011b).

To have a better tool for tracking emissions, the European Commission has established the "EU Building Stock Observatory", which presents several indicators regarding energy performance of buildings for every member state since 2011. One of these indicators is energy consumption in residential buildings. The temperature-adjusted value[i] for all energy use in 2014 was 173 kWh/m² in 2014

[i] Temperature-adjustment eliminates the influence of air temperature on energy use for heating. To eliminate this influence, a climate factor is introduced. A factor of 1.0 refers to an annual average equal to the long term

(EC, n.d.). This value is above the global average of 150 kWh/m² (cf. section 3.1.1).

A positive effect shown over the last two decades is a decrease in carbon intensity (EC, 2017, p. 119). It can be traced back to the share of renewable energy sources for heating, cooling and electricity, which has nearly doubled from 2005 to 2015 (EC, 2017, pp. 120-121).

Influences on GHG emissions within the residential building sector, which are more difficult to change and can therefore be seen as boundaries, are indicated at this level already. Generally, households in countries with a colder outside air temperature use more energy (Eurostat, 2017, p. 154). While the average energy consumption is declining slightly, there are some opposite trends with "higher levels of heating or cooling comfort, increased living space and increased use of electric appliances" (ibid., p. 154) producing an increase in GHG emissions.

3.1.3 In Germany

Estimates about the share of residential building sector in GHG emissions range from 10 % (UBA, 2017b) to 15 % (BMWi, 2015, p. 55). The exact numbers highly depend on the approach and the inclusion of indirect emissions and GHG other than CO_2.

The NIR gives estimates for the production-based approach. Since the year 2017, the NIR includes the residential sector separately under the key category Energy (UBA, 2017b, p. 112). This enables an understanding of the total amount of national GHG emissions originating in the combustion of fuels in the residential sector within German territory. These only include direct, operational emissions. They amounted to 86.7 Mt CO_2e in 2015 (ibid., p. 232), which is about 10 % of all national GHG emissions (cf. Figure 17).

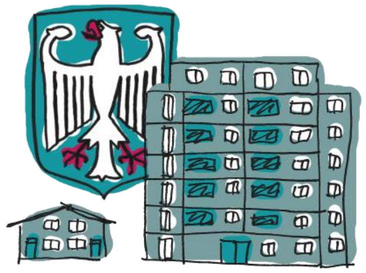

Figure 16: Illustration of Residential Buildings with the Federal Eagle of Germany (Author, 2018)

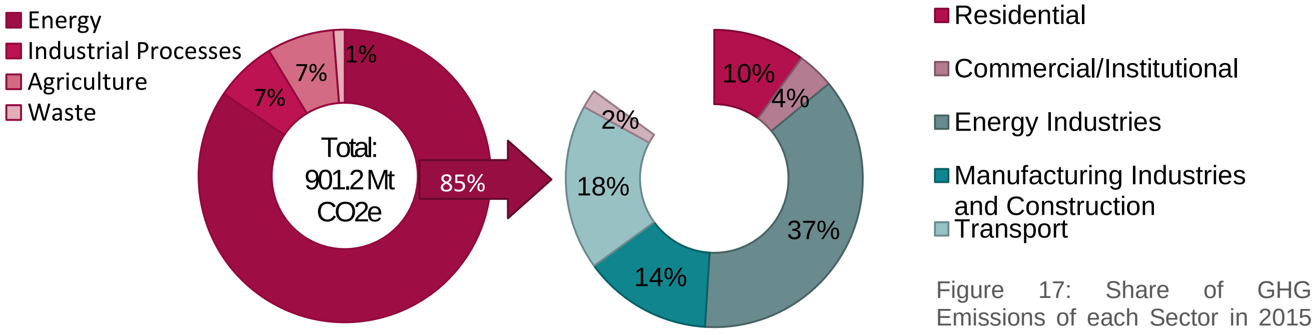

Figure 17: Share of GHG Emissions of each Sector in 2015 (adapted from UBA, 2017b)

average. A factor below 1.0 refers to a colder year, while a factor higher than 1.0 implies a higher annual temperature average. The multiplication of energy consumption by this factor enables a comparison of energy uses across years independent of outside air temperature. In 2014 actual energy use in residential buildings was only 159 kWh/m² (EC, n.d.), meaning it was an exceptionally warm year. In Germany the factor for temperature-adjustment is published by the German Meteorological Service (German: Deutscher Wetterdienst).

Indirect operational emissions of residential buildings are not specifically listed in the NIR. They can be found within the sub-sector Energy Industries, which includes the generation of electricity and heat. In total this sub-sector had a share of 37 % in GHG emissions in 2015 (cf. Figure 17), but the report does not allow the assignment to end users such as residential buildings. The amount of indirect emissions coming from residential buildings is therefore not possible to be taken from the NIR.

The Ministry for Economic Affairs and Energy estimated direct CO_2 emissions originating in the residential building sector to be 11.6 % and indirect CO_2 emissions from electricity and heating grids 3.8 % in 2011 (BMWi, 2015, p. 55), leading to a total share of 15.4 %. This estimate is also calculated according to the production-based approach.

Consumption-based estimates on emissions originating in energy use in private households can be found within the Environmental-Economic Accounting conducted by the Federal Statistical Office (in German: Umweltökonomische Gesamtrechnung). The tables comprise emissions only from CO_2, but since this gas represents the largest part of all GHG emissions, the calculated emissions still give an instructive insight on the amount of GHG emissions originating in the residential building sector. The study does not differentiate between emissions within German territory and abroad, but includes all direct and indirect emissions. Similarly to the NIR, the study also includes emissions occurring during the combustion of wood, while many other studies generally assume CO_2 emissions for renewable energy sources to be zero (Fehrentz, 2018c).

Consumption-based approach:
the residential building sector emitted
212.8 Mt CO_2 in 2015
(direct and indirect)

The Federal Statistical Office only began to track emissions in 1995 for private households, which is why the development of residential emissions is only shown for the period from 1995 to 2015 (cf. Figure 18). Estimates for the years before 1995 cannot be made. Due to the consumption-based approach, the calculated amounts of direct emissions in 2015 are higher than the 86.7 Mt CO_2 as calculated in the NIR. They reached 119 Mt of CO_2 in 2015 with an additional 93 Mt CO_2 for indirect emissions, leading to a total of 212.8 Mt CO_2 (Destatis, 2017e, p. 50). Consequently, total emissions consisted of 56 % direct and 44 % indirect emissions.

The development of consumption-based emissions shows only slight changes. For the years from 1995-2000 an increase was recorded, followed by an overall decrease. Presumably, increasing living area per person and an increasing share of single person households have led to the rise until 2000. In 2000, energy saving measures, such as modern heating systems, retrofitting and more efficient electronic devices, could possibly have intervened. The stagnation could mean that saving measures have reached their limits. Rather abrupt changes from 2010 to 2015 could not be explained (Fehrentz, 2018c).

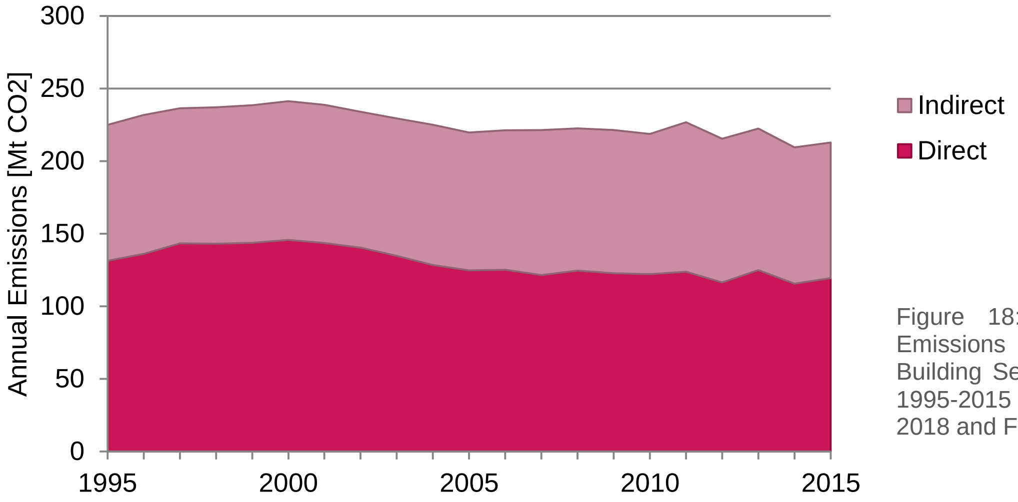

Figure 18: Consumption-based Emissions of the Residential Building Sector in Germany from 1995-2015 (adapted from Scheib, 2018 and Fehrentz, 2018)

The so-called decomposition analysis (cf. section 3.3.6) was only available for intervals of five years. An analysis of the emission factors by application showed a similar pattern in lighting (cf. section 3.4.2), but is not explained in full detail. Overall the decrease results in a 5 % decrease in 2015 opposed to 1995[I].

Contrary, according to the NIR, the decrease of residential emissions amounted to 34.5 % relative to 1990 (UBA, 2017b, p. 73). This difference cannot only be explained by the different reference years. It could be traced back to the different accounting methods. The reason for the 34.5 % decrease in production-based emissions could be an increase in imports. Consumption-based emissions would however not be influenced by these kinds of changes.

Despite past restrained reductions, the Federal Government has formulated the goal to achieve a nearly climate-neutral building stock in 2050 (Deutsche Bundesregierung, 2010, p. 2). "Nearly climate-neutral" means a reduction of primary energy use of 80 % relative to 2008[II]. CO_2 direct emission savings in residential and non-residential would amount to 246 Mt (81 %) relative to 2008 (ibid., p. 56).

To meet this goal, a doubling of the energetic renovation rate is needed (Deutsche Bundesregierung, 2010, p. 2). In accordance with the European Directive 2012/27/EU, Germany has developed a retrofit strategy to record efforts and achievements in the energy performance of its building stock (BMWi, 2017a). Final energy consumption in residential buildings in Germany was approximately 170 kWh/m² in 2014 (BMWi, 2015, p. 30; EC, n.d.), which was above the European average (cf. section 2.5.2). For a nearly climate-neutral building stock, the value needs to reduce to at least 104 kWh/m² by 2050 (BMWi, 2015, p. 51). While some studies assume the maximal reduction goal to be 74 kWh/m² (ibid., p. 48), others aim for up to only

For a climate-neutral building stock, final energy consumption for heating and hot water in residential buildings in Germany needs to decrease to at least 104 kWh/m².

[I] 212.8 Mt CO_2 / 224.9 Mt CO_2 = 94.60 %

[II] Which was 876 PJ/a (BMWi, 2015, p. 36) = 243 TWh/a

50 kWh/m² (Bürger et al., 2016, p. 172). Not all studies define the included energy uses precisely (such as Bürger et al., 2016), but usually these estimates only include final energy uses for heating and hot water (cf. BMWi, 2015, p. 37) and leave out electricity.

Efficiency measures are complemented by a rising share of renewable energy. Currently, the national share is above the European average for electricity and below the European average for heating and cooling (EC, 2017, pp. 120-121). When final energy use is high, the share of renewables needs to rise, so that the goal regarding primary energy is still achieved. This interdependency is expanded on in section 3.5.

3.1.4 In Hamburg

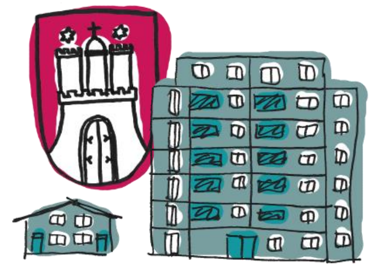

Figure 19: Illustration of Residential Buildings with Hamburg's Coat of Arms (Author, 2018)

At the city-level, all statistics are again presented according to the consumption-based approach. Based on the annual energy and CO_2 accounting papers published annually by the statistical office for Hamburg and Schleswig-Holstein (called Statistikamt Nord) the share of emissions of the residential building sector in total emissions in Hamburg can roughly be estimated. Proceeding in 5-year intervals, papers are available for the years 1990 (Tietje & Teunis, 2018a), 2005 (Tietje & Teunis, 2016a), 2010 (Tietje & Teunis, 2016b) and 2015 (Tietje & Teunis, 2018b). The data on emissions deriving from private households also include emissions caused by electricity use. Indirect emissions therefore seem to be at least partly included.

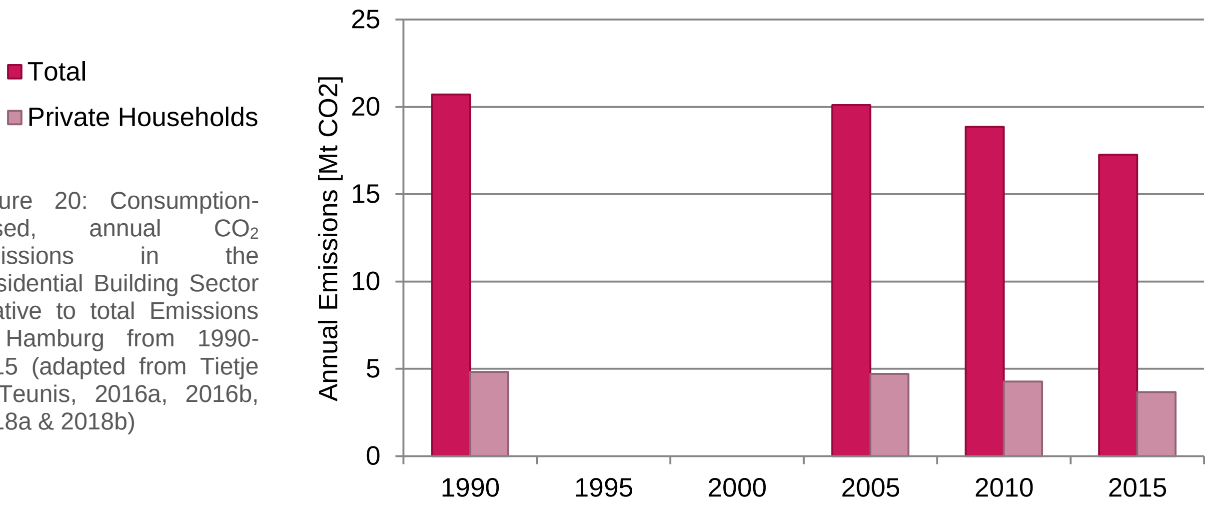

Figure 20: Consumption-based, annual CO_2 Emissions in the Residential Building Sector relative to total Emissions in Hamburg from 1990-2015 (adapted from Tietje & Teunis, 2016a, 2016b, 2018a & 2018b)

Figure 20 visualizes emissions of residential buildings in relation to total emissions of the energy sector in Hamburg. Both have decreased by approximately the same rate. As illustrated, the share of residential emissions is around a fifth of total emissions. However, the total emissions only represent the energy sector. If emissions from waste, agriculture and industrial processes were included in total emissions, the share of residential emissions would be slightly reduced to be approximately 18 %[I].

Similar to the national level, the share of residential emissions highly depend on whether indirect emissions are included, what total emissions comprise and if numbers are based on the consumption-based or the production-based approach. Based on previous studies, the share can be quantified between 10 % and 20 %.

In comparison with 1990, private households in 2015 have reduced their annual emissions by 1.2 Mt CO_2, which is nearly 25 %[II]. Assuming that the decrease was even over all years and in all sectors, it would have had to amount to 30 % to reach the goal of a 50 % reduction by 2030 (cf. section 2.5.4).

As explained in section 2.5.4, mitigation action in Hamburg is currently mostly tracked with the help of the bottom-up accounting method. According to this method, 0.048 Mt CO_2 were saved within the residential building sector in 2013 and 2014[III] (Bürgerschaft der FHH, 2015, pp. 74-75). This was approximately 1 % of residential emissions in 2015. Generally, the building sector is defined as an important field of action, since a quarter of final energy consumption originates there (Bürgerschaft der FHH, 2015, p. 28).

Just as the nationwide goal, Hamburg aims to have a nearly climate-neutral building sector by 2050. For this purpose, final energy use for heating and hot water of single family houses is supposed to reduce to 45-55 kWh/m² and that of multi-family houses to 40-45 kWh/m² (ibid., p. 28). According to the "Alliance for Living" in Hamburg (in German: Bündnis für das Wohnen), this leads to an interim goal of reaching 128 kWh/m² and 29 kg CO_2/m² [IV] by 2020 (Senate FHH et al., 2016, p. 13). These targets on energy use are much stricter than those at the national level. However, there is currently no published monitoring system that matches actual energy use with these anticipated values.

Emissions from residential buildings in 2015 were 18 % of total emissions. Relative to 1990, they have decreased by nearly 25 %.

Hamburg's target is to reduce final energy use for heating and hot water in residential buildings to 40-55 kWh/m² by 2050.

[I] The share of residential emissions in 2015 was 3.7 Mt CO2 / 17.3 Mt CO2 = 21.18 %. If non-energetic sectors were included, total emissions would rise by a factor of 1.18 (cf. section 2.5.4) to 17.3 Mt CO2 * 1.18 = 20.4 Mt CO2. The share of residential emissions would then be 3.7 Mt CO2 / 20.4 Mt CO2 = 17.95 %.

[II] 4.823 Mt CO_2 in 1990 - 3.657 Mt CO_2 in 2015 = 1.166 Mt CO_2 difference; 3.657 Mt CO_2 / 4.823 Mt CO_2 = 75.82 %

[III] A total of 0.6 Mt CO_2 was saved in 2013 and 2014, of which 8 % occurred in the building sector. 0.6 Mt CO_2 * 0.08 = 0.048 Mt CO_2

[IV] Including hot water

3.2 GHG Emissions during the Life Cycle of Residential Buildings

As shown in section 3.1.3, according to the consumption-based approach, residential buildings in Germany have directly and indirectly emitted 212.8 Mt CO_2 in 2015. As the definition of the consumption-based approach (cf. section 2.4) describes, the place of occurrence is not designated. The emissions occur within Germany as well as abroad. The estimate only takes into account operational emissions. To get a complete picture, this chapter will take a detailed look at additional emissions occurring before, during and after usage. Only emissions from construction, retrofit, demolition and for heating and electricity during usage are taken into account. Emissions resulting from the management of water, manure and waste are not considered. Also, emissions from the conversion of land, for example from forests and grasslands to settlements (UBA, 2017b, p. 636) are not included.

3.2.1 During Construction

Referring to the NIR, emissions from the manufacturing of construction materials are “hidden” in other sectors. They are allocated to the sector of Industrial Processes, which is divided into the production of different materials (UBA, 2017b, pp. 294-406). Emissions for the transportation of construction materials amounted to 3.3 Mt CO_2e (UBA, 2017b, p. 200) and 9.5 Mt CO_2e for construction works in 2015 (Destatis, 2017d, p. 21). However, neither of these gives further insight on the share, which was used in the residential sector only.

Another approach to receive an approximate number of how much GHG emissions arise through construction is by referring to existing studies on so-called embodied emissions in residential buildings. Worldwide, the value varies from 179 kg CO_2 to 1050 kg CO_2 per square metre of living space (Chastas et al., 2018, p. 223). In a case study on low-energy buildings in Austria, the average of solid construction buildings was 542 kg CO_2e/m² referring to living space (Passer et al., 2012, p. 115; cf. Appendix A). The value includes all emissions for products and services (ibid., p. 1119), some of which are likely to take place in other countries. The studied buildings have a high energy standard that demand more input and emissions during construction. The estimation is consequently rather high, but will be used in the following analysis.

Total living area in Germany amounted to 3,794,976,000 m² in 2015 (Destatis, 2017c, p. 13). In the same year, 23,892,000 m² (0.6 %) of living space was built and 3,355,000 m² (0.1 %) of existing living space was rebuilt (Destatis, 2017b, p. 15). The approximate GHG emissions resulting from construction of residential buildings can be calculated by multiplying construction activity with the value for embodied emissions per living area. This leads to 14.8 Mt CO_2e[I], which was emitted by the construction activity in the residential sector inside and outside of Germany in 2015. It should be noted that this is a very rough estimate, with the sole purpose of giving an approximate idea of the impact of construction activity in the residential sector.[II]

3.2.2 During Energetic Renovation

The energy standard of a building highly influences its energy use. Energetically improved walls, roofs, windows and doors can reduce final energy uses of residential buildings in Germany to less than 70 kWh/m²a (Bürger et al., 2016, p. 126, 130). Energetic renovation measures reduce operational energy use and therefore GHG emissions. Yet, additional GHG are emitted when the new materials are manufactured, transported and disposed at their end of life. Since there is no inventory on performed retrofits, total emissions resulting from renovations are difficult to estimate. Instead, the benefit of retrofits can be expressed in their pay-off.

In a study from 2016 funded by the Federal Ministry for Education and Research, scientists took a closer look at GHG investments in retrofits. They found that embodied GHG emission of insulation per square metre of floor space varies from 3.6 kg CO_2e/m^2 for cellulose to 14.4 kg CO_2e/m^2 for expanded polystyrene (EPS) (Dunkelberg & Weiß, 2016, p. 30), whereas the installation of new windows embodies on average 7.8 kg CO_2e/m^2 (ibid., p. 31). One-time retrofitting measures lead to annual emission savings of up to 24 kg CO_2e/m^2 (ibid., p. 32). Amortisation periods depend on the building age and type and the retrofitting measurement. In buildings constructed before 1990 the additional GHG emissions induced through insulation are usually amortised after less than a year. Buildings erected after 1990 were already equipped with better insulation, which is why the amortisation period of insulation increases to around two to seven years. In all buildings, the exchange of windows is amortised after between 1 to 11 years (ibid., pp. 34-35). In regards to heating systems, GHG emissions from the phases of manufacturing, transport and end of life are irrelevant in comparison with their operational emissions (ibid., p. 39). Their replacement with a more efficient device pays off almost immediately.

Nevertheless, another important aspect besides emissions affecting the climate is the impacts on the environment. According to the UBA,

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[I] (23,892,000 m² + 3,355,000 m²) * 542 kg CO_2e/m^2 = 14.8 Mt CO_2e

[II] According to the study by Passer et al. (2012), low energy buildings emit 45.6 kg CO_2e/m^2 during operation. This would lead to 3,794,976,000 m² * 45.6 kg CO_2e/m^2 = 173.1 Mt CO_2e of emissions in Germany in 2015. This value is lower than the estimated 212.8 Mt CO_2, since the energy standard of the studied buildings is lower than the national average. The difference would be higher if both estimates used the same unit (CO_2 or CO_2e).

the use of insulation materials is climaticly the only option. The decision is consequently not between climatic and environmental demands, but already made towards climatic needs with the challenge to reduce environmentally toxic impacts (Bürger et al., 2016, p. 69). All in all, despite needed emission investments and possibly environmental impacts, short amortisation rates with continuous emission savings justify retrofitting measures. Total emissions in Germany resulting from retrofits cannot be quantified, but due to their short pay-off times, the appropriateness of emission investments for retrofitting measures will not be questioned in this paper.

3.2.3 During Demolition

Due to limited research, the emissions originating in demolition of residential buildings are calculated similarly to those originating in construction (cf. section 3.2.1). The Austrian study conducted by Passer et al. in 2012 examined low-energy and passive houses. Due to their high energy standards, their demolition is likely to be more emission intensive than the demolition of buildings with lower energy standards. The following calculation is therefore likely an overestimation. Emissions during demolition of residential buildings with solid construction amounted to approximately 126 kg CO_2e/m2 per living area (cf. Appendix A). In Germany in 2015, the amount of demolished living space was 1,942,000 m² (Destatis, 2017c, p. 22). This leads to a total of 0.2 Mt CO_2e emissions resulting from demolition work on residential buildings in Germany.

3.2.4 GHG Emissions in Proportion

Emissions from construction and demolition were determined in CO_2e, while operational emissions were given in CO_2. Thus, the latter would be higher if other GHG were included as well. However, to provide an approximate estimate of proportional shares, all three estimates are compared. When added up, the amount of total emissions is 227.8 Mt CO_2(e). Figure 21 illustrates an overview of the shares of emissions in the three phases of a life cycle of buildings in Germany. It can clearly be seen that operational emissions have the largest share of total emissions. In 2015, over 90 % of all emissions occurring in the residential building sector can be allocated to the operational phase. In reality, the share of emissions during operation is even higher, since GHG other than CO_2 are not included in the illustration.

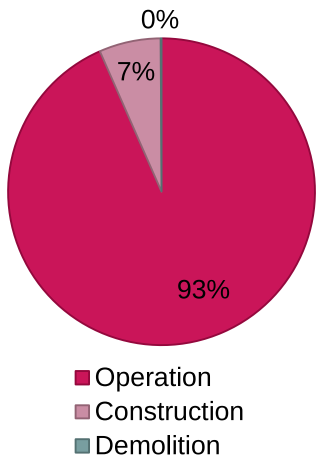

Figure 21: Share of GHG Emissions in Germany in 2015 deriving from the Residential Building Sector for Operation, Construction and Demolition (Author, 2018)

In places like Hamburg, where most buildings have been built already, the share of emissions during construction decreases further. Due to their high share in total residential emissions, operational emissions should be at the centre of consideration regarding emission savings. This finding underpins the focus of the case study on only the existing building stock and its energy use.

3.3 Operational Energy Use in Residential Buildings

As shown in the previous section, the largest share of emissions in the residential building sector occurs during the operational phase. The remainder of this paper will therefore focus only on operational activities, neglecting emissions from construction, retrofitting and demolition.

This subchapter explains some basics on energy use and gives an overview on total amounts of energy use in the residential sector from 1995 to 2015. Since energy consumption and emission data in Hamburg is not available for all years (cf. section 2.5.4) and not in extensive detail (cf. Tietje & Teunis, 2018b, p. 15), all statistics used are national statistics.

The amounts are further split by application and by source, so that a very detailed picture on the total operational energy use in private households can be obtained. The chapter will end with a detailed examination of influencing factors on energy use based on existing studies.

3.3.1 Energy Terms

In order to understand energy quantities, the different forms of energy need to be understood. From its origin to its end use, energy runs through several levels. In its crude constitution, energy is called primary energy. It is then transformed to secondary, then to final and in the end to net or effective energy.

The first level describes energy at its source when it has not yet been transformed. Instead of primary energy it is also known as crude energy. Examples of primary energy take the form of raw oil, natural gas, nuclear power and coal. When looking at renewable energy sources, primary energy depicts sunlight, wind, vegetation or streaming water.

Primary energy can be transformed to secondary energy, which is also referred to as energy carrier, since it enables energy to be moved from one place to another. Secondary energy can take the form of fuel oil, hydrogen and electricity.

Final energy is the energy that reaches the end user, as found in private households. For example, heat from district heating, gas or electricity is final energy.

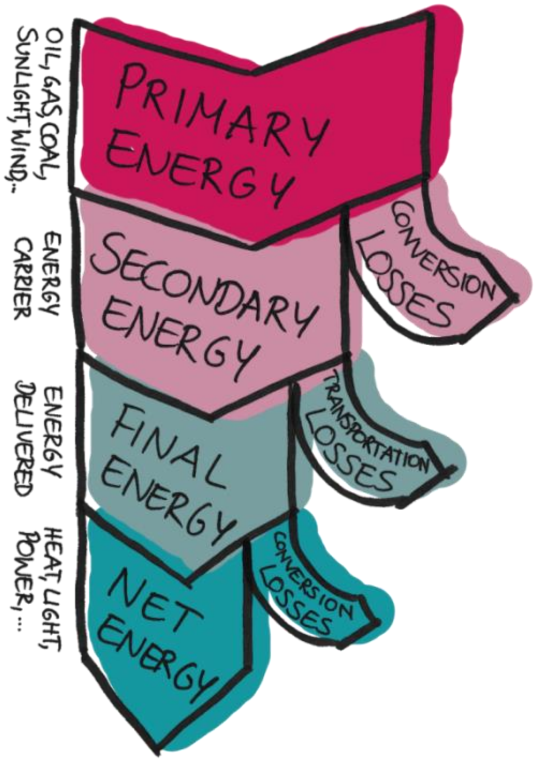

Figure 22: Processing steps of energy (Author, 2018, based on Marquardt, 2011, p. 20; VDI-GEU, 2012, p. 4-5)

Net energy, or effective energy, is the last step after previous conversion and transportation. In the sector of private households, this term refers to the heat coming from radiators, light and mechanical work devices such ashair dryers.

Shares of energy get lost through the different levels by conversion and transportation. Of all primary energy uses in

Germany in 2016, as well as within the sector of private households alone, over 30 % were lost during the conversion to final energy (BMWi, 2017b; Destatis, 2017e, p. 42). The amount of these losses depends on the energy source. To quantify losses along the way, so-called primary energy factors indicate the ratio from primary energy to final energy. For heat energy in Germany, they range from 1.5 for biogas to 1.0 for renewable energy sources (DIN V 18599-1). Renewable energy sources basically have no losses, because it is assumed that their sources cannot be depleted. Sunlight and wind for example cannot be used up, but will always be there, no matter if being used for energy generation or not.

Consequently, the more renewable energy sources are used, the lower the primary energy factor. The official factor of the energy mix of electricity in Germany has decreased from 3.0 in 2002 to 1.8 in 2016 due to an increasing share of renewable energy sources (Schüwer et al., 2015, p. 30). The factors can also be calculated manually based on data on primary and final energy published by the Federal Statistical Office (Destatis, 2017e, p. 42). The calculation leads to a primary energy factor for electricity in private households of 2.5 in 2015. The Federal Ministry for Economic Affairs and Energy expects the primary energy factor for electricity to decrease further to 0.4 in 2050 (BMWi, 2015, p. 35).

3.3.2 Total Energy Use

The following analyses will only focus on final energy use in residential buildings. It should therefore be kept in mind that this implies only to the energy delivered to the households, which is 70 % of primary energy use. The other 30 % of energy have been lost through conversion and transportation (Destatis, 2017e, p. 42).

The annual final energy use in private households has been tracked by the Federal Statistical Office for all years since 1995 (cf. Destatis, 2017e). The amounts are temperature-adjusted to ensure comparability. In 1995, the amount of final energy use was at just over 700 TWh. It increased until the year 2000 and has mostly been declining ever since. In 2015, the amount was at approximately 650 TWh.

Energy use depends on the number of users and the amount of used space. To see energy consumption independent from these factors, it can also be expressed in energy use per person or per square metre of living area (cf. Figure 23).

The total area of living space in Germany has risen from 3.0 billion m² to 3.8 billion m² (Destatis, 2017c). Consequently, final energy use per square metre has decreased over time from approximately 240 kWh/m² to 170 kWh/m² (cf. Figure 23). When using the unit of energy consumption per living area, technical advances in energy saving can be seen. With an increase in living space however, it neglects the fact that total energy savings are much smaller than energy savings per square metre.

The number of inhabitants by contrast has only slightly increased from 81.5 million to 82.2 million from 1995 to 2015 (Destatis, n.d.). This rather stable component leads to a final energy use per capita developing over time similarly to total energy use (cf. Figure 23). The unit of energy consumption per capita can be used, when consumption rates on a personal level are of interest. It harmonises with the approach shown in section 2.5.5, where energy use was expressed per capita to ensure comparability and express responsibility. On these grounds, statistics of this chapter as well as in the case study will be presented in emissions per capita.

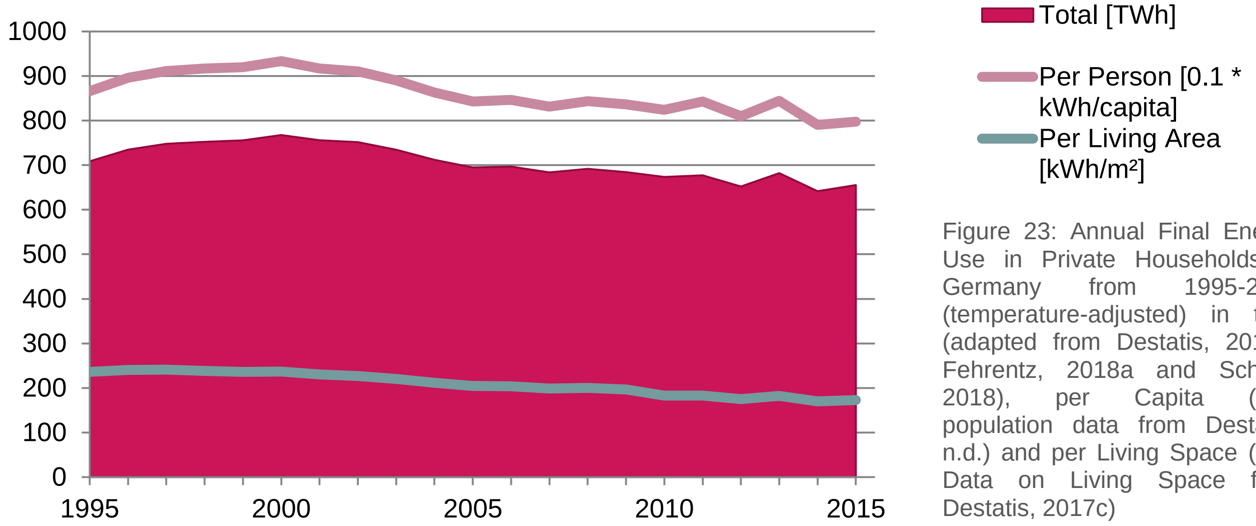

Figure 23: Annual Final Energy Use in Private Households in Germany from 1995-2015 (temperature-adjusted) in total (adapted from Destatis, 2017e, Fehrentz, 2018a and Scheib, 2018), per Capita (with population data from Destatis, n.d.) and per Living Space (with Data on Living Space from Destatis, 2017c)

Overall, Figure 23 has shown that from 1995 to 2015 considerable energy saving was achieved in energy use per living area. But since living area has increased over time, reduction of total energy use in residential buildings was rather restrained. This can be seen both in total amounts of consumption as well as consumption per capita.

3.3.3 By Application

To understand the composition of energy use in residential buildings, the total amount can be split into usage by application. This evaluation cannot be made for Hamburg specifically due to lack of data (Tietje & Teunis, 2018b, p. 6). The data of national energy use by application is also published by the Federal Statistical Office (cf. Destatis, 2017e) and based on calculations from the scientific institute RWI in Essen[I]. The following categorisation for applications is made:

Space Heating	
Hot Water	
Other Process Heat	Mostly cooking, including hot water for dishwasher and laundry machine
Mechanical Energy	Electronic devices, including cooling and freezing, devices for communication and entertainment
Lighting	

Table 1: The Classification of Applications used for Statistics of Energy Consumption (adapted from Destatis, 2017e)

The development of final energy use per person from 1995 to 2015 split by application can be seen in Figure 24. The maximum was more than 9,300 kWh in 2000. It dropped back to approximately 8,000 kWh in 2015.

By far the largest part of energy was used for space heating. In 1995, three quarters of all energy consumption was used for this purpose. This share decreased slightly between 1995 and 2015. It is remarkable that most changes in the total amount seem to originate in changes in space heating. The need for space heating, in a similar manner to the total, increased from 1995 to 2000 and then constantly decreased with some irregularities in 2012 and 2013. Regarding the large share of space heating, it should be kept in mind that the heating period in Germany lasts only from October to April (Sandrock, 2014, p. 15). So it is around seven months long, meaning that all energy for space heating is used during this time.

The application with the second largest energy demand is hot water. Unlike space heating, its amount of energy use was constant over time. One eighth of all energy use originates here.

The amount of energy use for cooking, dish washing and laundry has increased by nearly 50 % from 1995 to 2004 and has been almost

[I] Explanations for the years 2014 and 2015 for example can be found at RWI - Leibniz-Institut für Wirtschaftsforschung, 2016 constant since. In 2015 around 6 % could be attributed to this category, which is called “other process heat”.

The category of mechanical energy describes the use of electronic devices in households. In the considered time period, energy use for this application increased by 20 %. In 2015 its share in total energy use was approximately 9 %.

Energy use for lighting was very constant over time with a slight increase around the year 2006. With only 1.6 % it has the smallest share in final energy use in private households.

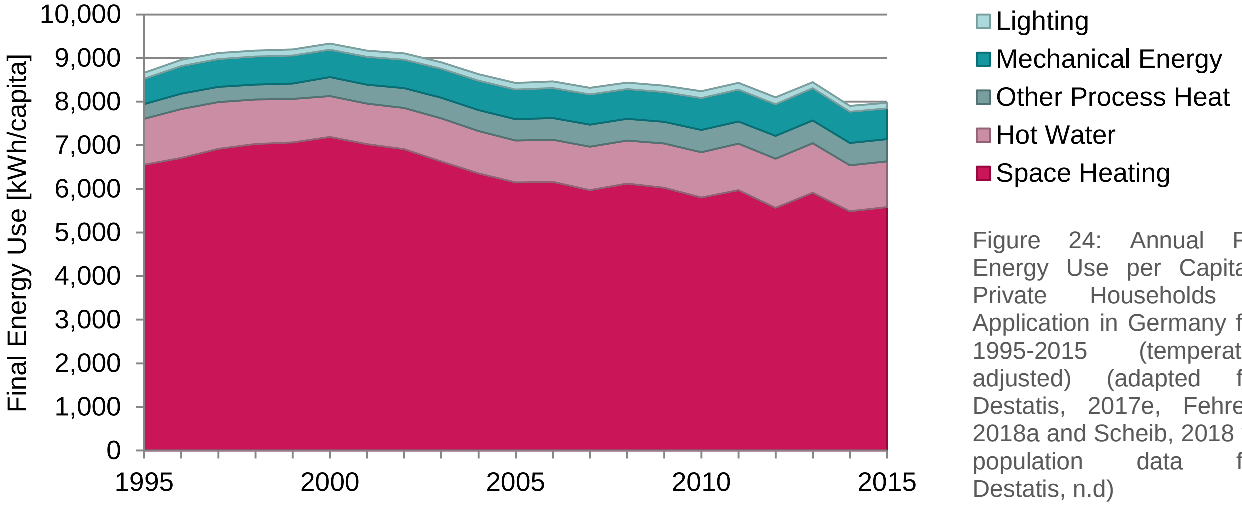

Figure 24: Annual Final Energy Use per Capita in Private Households by Application in Germany from 1995-2015 (temperature-adjusted) (adapted from Destatis, 2017e, Fehrentz, 2018a and Scheib, 2018 with population data from Destatis, n.d)

3.3.4 By Source

Used energy derives from several sources. Figure 25 shows the development of energy sources in private households from 1995 to 2015. The most obvious development is a reduction of petroleum and an increase in “other”. The latter implies renewable energy (Fehrentz, 2018c). The share of coal is extremely small. It probably refers to old buildings, which still use coal for heating or have a coal burning stove (Tietje, 2018).

In total in 2015, nearly 40 % of all energy in private households was generated by gas, 20 % by petroleum, and another 20 % by electricity. 12.5 % can be assigned to “other” sources, 8 % to district heat and only 1 % to coal (cf. Destatis, 2017e, p. 46).

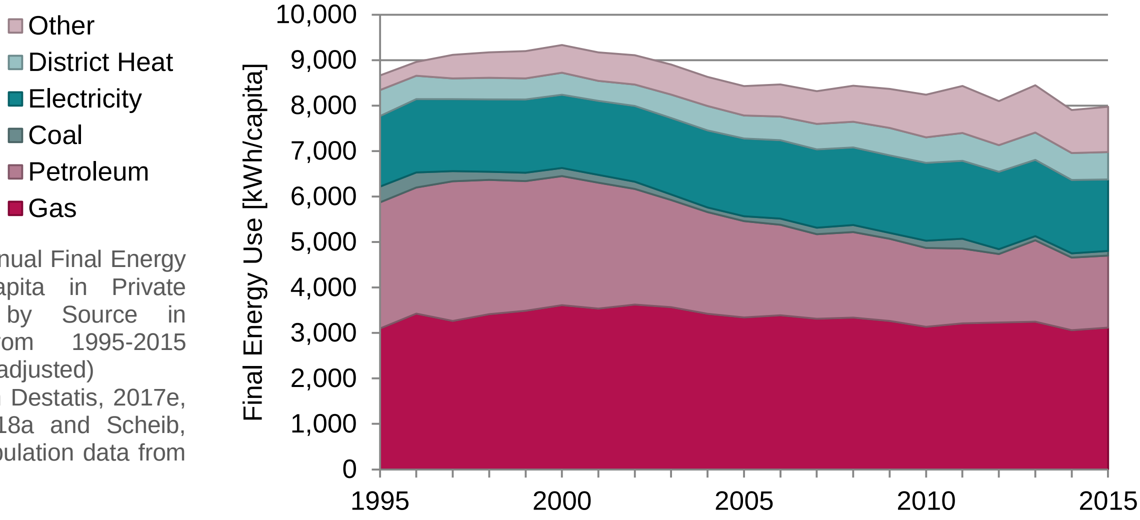

Figure 25: Annual Final Energy Use per Capita in Private Households by Source in Germany from 1995-2015 (temperature-adjusted) (adapted from Destatis, 2017e, Fehrentz, 2018a and Scheib, 2018 with population data from Destatis, n.d)

Energy sources for district heat depend highly on local conditions. The mix for district heat in Hamburg specifically is shown in Figure 26. The section “renewables” mainly consists of biogenic waste (Tietje, 2018). Here, “other” stands for steam, more specifically heat. Steam, which is produced elsewhere, is converted to hot water at the transition point to the district heat grid (Tietje, 2018).

The electricity mix that the statistical office uses in Hamburg is identical with the national one (Tietje, 2018). Figure 26 therefore shows the national electricity mix, which can also be applied in Hamburg. Both energy mixes have a large share of coal, which is composed of hard coal and lignite.

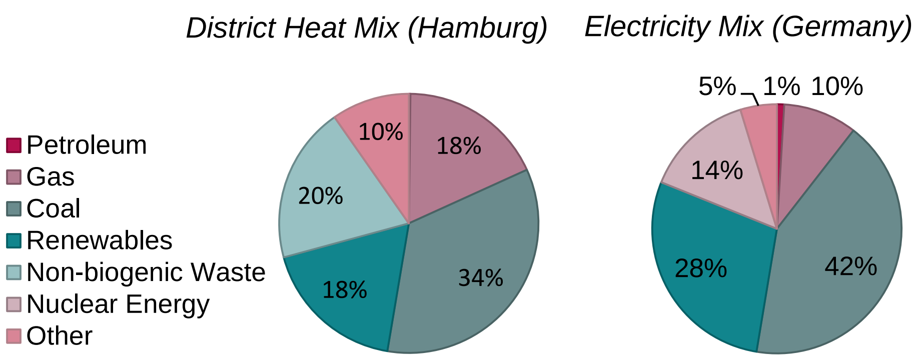

Figure 26: Composition of Sources for District Heat generated in Hamburg in 2015 (Tietje,, 2018) and the National Electricity Mix in Germany 2015 (adapted from Destatis 2017e, p. 38)

The composition of energy sources of electricity in Germany has changed in a sense that since 1990 the share of coal and nuclear energy has decreased, while the share of gas and renewable energy sources has increased (Icha & Kuhs, 2017, p. 19).

The mix of energy sources is important when a country or a municipality strives to mitigate GHG emissions. However, as the electricity mix has shown, it is not always possible to break down energy uses into sources at the local level.

3.3.5 By Application and Source

A further breakdown can be achieved when sources are added to each application (cf. Figure 27). The categories of lighting, mechanical energy and other process heat consist mainly of electricity. Regarding space heating and hot water, approximately three quarters of energy were generated by petroleum and gas. For hot water the rest is mainly generated by electricity, while for space heating the other two major sources are district heat and renewable ("other") sources.

As noted before, the largest changes took place in the usage of petroleum, coal and renewable sources for space heating. The amount of used petroleum and coal has decreased, while renewable sources increased.

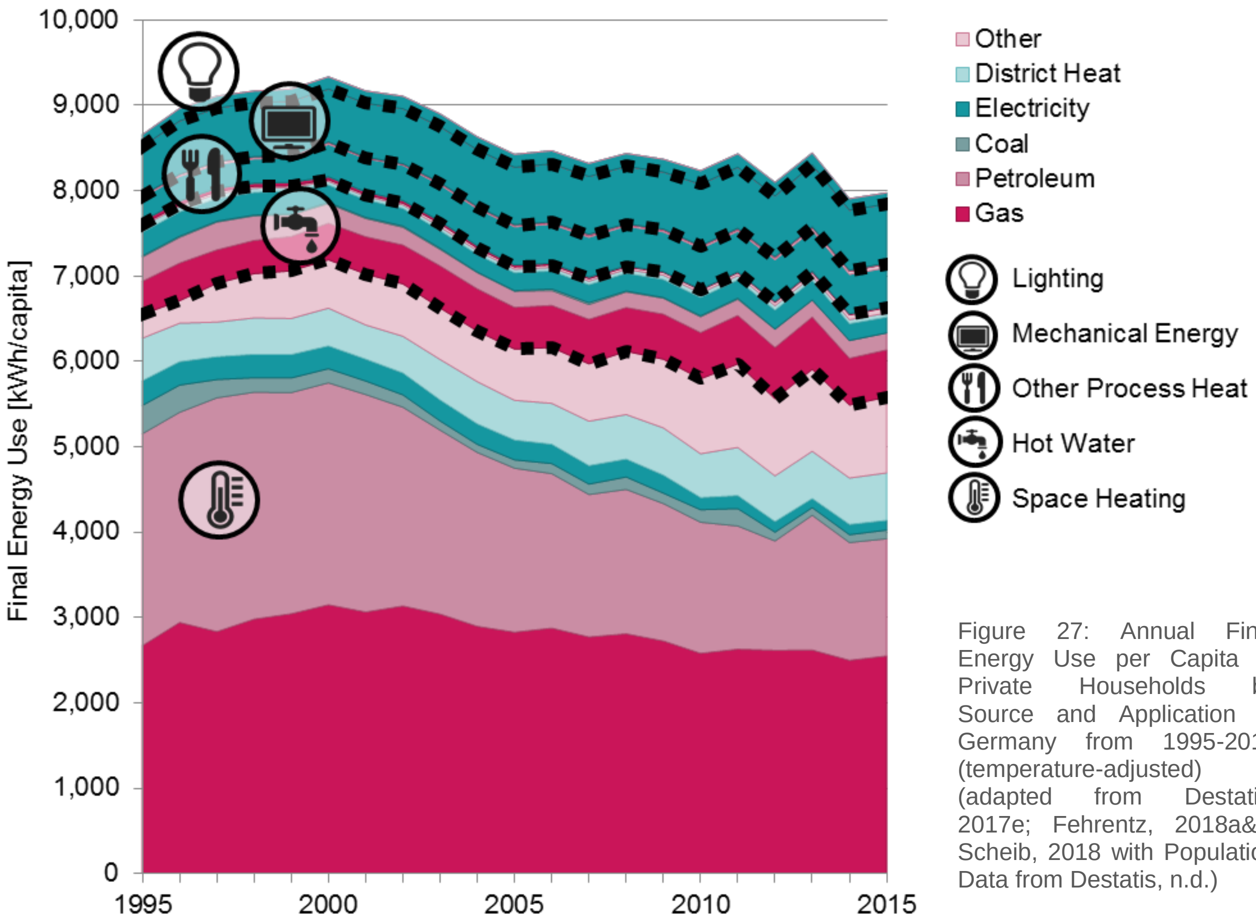

Figure 27: Annual Final Energy Use per Capita in Private Households by Source and Application in Germany from 1995-2015 (temperature-adjusted) (adapted from Destatis, 2017e; Fehrentz, 2018a&b; Scheib, 2018 with Population Data from Destatis, n.d.)

3.3.6 Influencing Factors on Final Energy Use

In the preceding chapters changes in energy use were shown. Since the year 2000 energy use in the residential sector has slowly been decreasing, resulting in a decrease in energy use per capita from 9,400 kWh to 8,100 kWh in 2015 (cf. Figure 24). What are the drivers of changes in energy consumption?

Energy is directly influenced by the number and type of equipment and the times of use. These factors in turn are influenced by several other factors, which have been analysed in many studies (Delzendeh et al., 2017, p. 1067; Deutsch & Timpe, 2013). This section will present an overview of research without claiming completeness.

Energy used for heating extremely depends on climatic parameters (Delzendeh et al., 2017, p. 1066). The dependence on outside air temperature has also been proven for households in Germany (UBA, 2014, p. 65). Residential energy use usually increases during cold winters such as the winters of 1996, 2001 and 2010, which lead to a more intense heating period (UBA, 2016; UBA, 2017b, p. 233). To keep the ability of comparing energy use in different years, measured consumption data is usually temperature-adjusted (cf. explanation in section 3.3.2).

> From a technical perspective, the main influencing factors on energy use concern urban structure, building age, energy standard and electric equipment.

Regarding the urban structure of residential buildings, a US-American study found immense differences in energy use per capita depending on the setting (Nichols & Kockelman, 2014). Residents in suburban settings consumed much more energy than residents in dense, urban neighbourhoods. The observation is true not only for operational but also embodied energy in the construction. The researchers suggest that high population density and small apartments could offer great energy savings.

When it comes to the building stock in Germany, single family houses have the highest energy use per square metre. The energy use of apartment buildings is slightly lower, while that of apartment blocks tend to have the lowest energy demand (Bürger et al. 2016, p. 130). Similar results were found in a Danish study (Brounen et al., 2012). The difference between the three building types decreases after retrofitting (Bürger et al. 2016, p. 130). On a national average, in 2014 single and two-family houses used approximately the same energy per square metre, while multi-family houses tended to be slightly more efficient (Destatis, 2017e, p. 54).

This effect is linked to the shape of a building. Large multi-family houses have a smaller building envelope relative to the building's volume. Generally, large surfaces permit higher transmission heat losses. Energetically, the best shape is a spherical building, followed by a large cube (Grimm, 2016; Marquardt, 2011, p. 40). These shapes have a small surface in comparison with the volume they hold. For example, changing the floor plan of a building from a square to an H shaped floor plan increases the energy use by 15 % (Bostancioglu, 2010, p. 465).

Old buildings can use two to four times more energy per square metre than new ones (BMWi, 2015, p. 30; Brounen et al., 2012; Bürger et al., 2016, p. 130). Following to the introduction of energy regulations (cf. UBA, 2011, p. 82), building age groups can be formed (cf. section 4.4.1). According to Hamburg's current climate plan and national statistics, residential buildings constructed before 1978 have the greatest share in use of space heat and hot water (BMWi, 2015, p. 30; Bürgerschaft der FHH, 2015, p. 29). In Hamburg over 70 % of all buildings were built before 1978 (Bürgerschaft der FHH, 2015, p. 29).

The main driver for energy reductions within the residential building sector was "higher standards for new buildings [and] energy-efficiency-oriented modernisations of existing buildings" (UBA, 2016; UBA, 2017b, p. 233). Buildings with a high energy standard give off less heat and make use of more efficient technology. Thick insulation layers do not have a significant impact on cooling demand, but they reduce heating demand (Tabrizi et al., 2016, p. 132). As calculated in a study conducted by Fraunhofer ISE for residential buildings in Germany, refurbishments lead to a reduction in final energy demand of at least 50 % (Bürger et al., 2016, p. 130). These refurbishments imply first of all an improvement of the buildings envelope, and secondly an upgrade of technologies used for heating, cooling, lighting and ventilation (ibid., p. 128). Used energy sources consequently change over time. From the year 2000 to 2014, the share of apartments using heat pumps and district heat for example has increased from 8 % to over 40 % (BMWi, 2015, p. 24). Since heat pumps use renewable environmental heat, their primary energy factor is below 1,0 (BINE, 2013, p. 6).

In Germany the amount of large electric devices such as television sets, refrigerators and freezers, washing machines and dish washers has constantly increased. This has led to an increase in electricity use (UBA, 2011, p. 73). Opposingly, the introduction of LED lighting has led to a decrease of electricity use for lighting (ibid., p. 63).

Energy use is sometimes reduced to only technical questions, but socio-demographic factors also have a large impact on the amount of energy consumption. An important factor is the number of inhabitants per household. The more people share a household, the more energy is used per household, but less energy is used per person. This effect can be called economies of scale. It is true for both electricity and heat energy use (UBA, 2011, pp. 85-86). In 2015 a person in a single person household used over 11,000 kWh, while a person in a two-person household used only 8,400 kWh. With all other households combined, every person used just over 8,100 kWh on average for living (Destatis, 2017e, p. 51). This effect can also be seen in the so-called Stromspiegel, which presents average electricity use in

Socio-demographic factors also influence energy use. They mainly concern the number of people per household, living area per person, age of inhabitants and the financial situation.

Germany. It mainly depends on the number of people sharing a household and the type of building. When sharing the apartment with three other people, electricity consumption is only half the amount of a single-family household (cf. Appendix J). In Germany there is a tendency towards more households and fewer inhabitants per household, working oppositely to trends of energy savings (UBA, 2014, p. 67; UBA, 2016).

Even though fewer people tend to share a household, the size of apartments increases. The average size rose from 82 m² in 1990 to 92 m² in 2015 (Destatis, 2017c, pp. 5, 7). Both effects have led to an increase in the living area per person in the same time period from 35 m² to 46 m² (ibid., pp. 5, 7), lessening total energy savings (BMWi, 2015, p. 39).

Elderly people tend to consume more energy per capita. This could be due to thermal sensitivity, so that elderly people use more heat energy, but typically less electricity (Brounen et al., 2012). Another possible explanation is the large living area per elderly person, which arises when shrinking households are not adjusted (Deutsch & Timpe, 2013, p. 2180; Pätzold, 2018, p. 8). Elderly people also tend to live in older and therefore less energy-efficient houses (ibid., p. 2181). This example shows that a factor can be connected to several other ones. It is therefore hard to trace back consumption patterns to a specific cause.

While globally speaking economic growth can lead to high energy use (IPCC; 2014b, pp. 45, 48), locally, the opposite can be true, when high-income occupants can afford apartments with a higher energy standard (Delzendeh et al., 2017, p. 1067). Different studies have shown differences between subsidised housing and other rental places (ibid., p. 1067). Also, income does not have the same impact on all energy uses. In a Dutch study, electricity was more sensitive to changes in income than heat energy use (Brounen et al., 2012, p. 942). A study conducted in China calculated different independencies of income, employment rate and urbanization for different regions (Wang & Zhao, 2018). A global, overarching rule does not seem to exist.

The impact of human behaviour on energy use is hard to grasp.

The last factor is highly influential (Abergel et al., 2017, p. 10), but much harder to grasp if not impossible to estimate: human behaviour. It is shaped by so many parameters that it seems unpredictable and is therefore currently not quite considered yet in simulations (Delzendeh et al., 2017, p. 1068). Utilization periods for example are highly relevant but difficult to obtain (Gottschick, 2018). Yet, some studies worked out a number of specific properties. Education and awareness of energy issues for example, but also energy costs can reduce energy consumption (Delzendeh et al., 2017, p. 1067). Opposing behaviour changes can also occur, when energy efficiency measures have been performed. This can be called the “rebound effect” (BINE, 2015). Changes in human behaviour can seem arbitrary, or they can show general trends. Final energy for cooking for example has increased immensely (UBA, 2011, pp. 63, 87). The effect can partly be explained by changing technical devices, but also by behaviour change. Several scientists, such as Nord et al. (2018) and Yu et al. (2011), have worked on ways to influence occupant behaviour. Even though they are highly important, they will not be discussed in this paper.

It is clear, that innumerable factors affect the energy use in private households. Researchers have developed models, which are supposed to predict energy use. Scientists at the University of Toronto for example created a model for emissions resulting from heat energy use, electricity use and transport in all cities worldwide. It included the factors heating and cooling degree days, GDP and urbanized area per capita (Singh & Kennedy, 2015, p. 272).

A national model for space heating in private households is conducted by the Federal Statistical Office in the so-called decomposition analysis. It is not published, but can be received upon request. In the analysis, the development for space heating is traced back to the factors population development, household size, living area per household and energy intensity. The results are shown in Figure 28. It can be seen and has been shown in section 3.3.3 that overall energy demand for space heating has been decreasing in all periods. The decline was highest in the period from 2000-2005 and became smaller after. The main factor for this development was the development in energy intensity, which expresses energy use per living area (Strelau, 2018). In conclusion, the more efficient use of energy per square metre has led to a decrease in total energy demand. The positive effect of energy intensity was slightly diminished by developments in household size and living area per household. Total amounts of energy use rise with the number of users. However, population has been rather stable in Germany (cf. section 3.3.2). Changes in the population have therefore had only little influence on the energy demand for space heat.

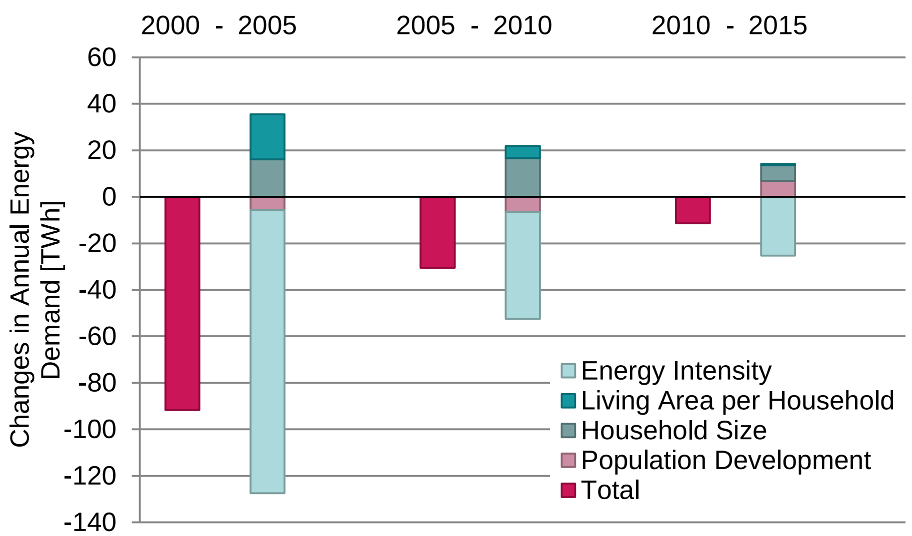

Figure 28: Changes in Annual Energy Demand for Space Heat (temperature-adjusted) by Influencing Factors in 5-year intervals from 2000-2015 (adapted from Strelau, 2018)

3.4 Operational GHG Emissions in Residential Buildings

During the process of generating, converting, transporting and using energy, GHG are set free. The amount of emissions varies from one energy source and technology to another. In order to understand and compare the climatic impact of different energy sources, the GHG emission factor can be used as indicator. It expresses the amount of emitted GHG per unit of final energy (Memmler et al., 2017, p. 146). It includes all emissions along the conversion from primary to secondary, final and net energy (ibid., p. 21). While direct emissions only quantify emissions during combustion, indirect emissions also express upstream and auxiliary energy emissions.

The IPCC provides CO_2 emission factors of several fuel types in their guidelines for the NIR. However, these do not include indirect emissions (Garg, 2006, p. 1.24). Instead, the Federal Environment Agency of Germany (in German: Umweltbundesamt, abbreviated: UBA) has conducted a study, in which not only direct GHG emissions but also those from the upstream chain and auxiliary energy are included (Memmler et al., 2017, pp. 80-121). However, the study assumes direct emissions resulting from renewable energy sources to be very low. This conflict will be explained in more detail. Additionally, the statistical office has published total CO_2 emissions of different applications in private households (Destatis, 2017e, p. 50) using emission factors used in the German NIR (UBA, 2018). The results of the studies will be presented in the following.

Within theses studies, similarities but also discrepancies can be seen. The reason lies in different assumptions of emissions of renewable energy sources. Additionally, due to uncertainties different studies lead to different results. In Germany's National Inventory Report a discrepancy of up to 5 % is shown (UBA, 2017b, p. 154). The numbers should therefore always only be seen as approximate indicators.

3.4.1 Total Emissions

Total operational, consumption-based CO_2 emissions, divided into direct and indirect emissions, were already presented in section 3.1.3 and are analysed further in this chapter. Changes over time are similar to the development of energy consumption as shown in section 3.3.2. In general, the amounts are rather stable with a slight reduction since 2000. The very sudden changes since 2010 are looked at in more detail in the following, but stay mostly unexplained.

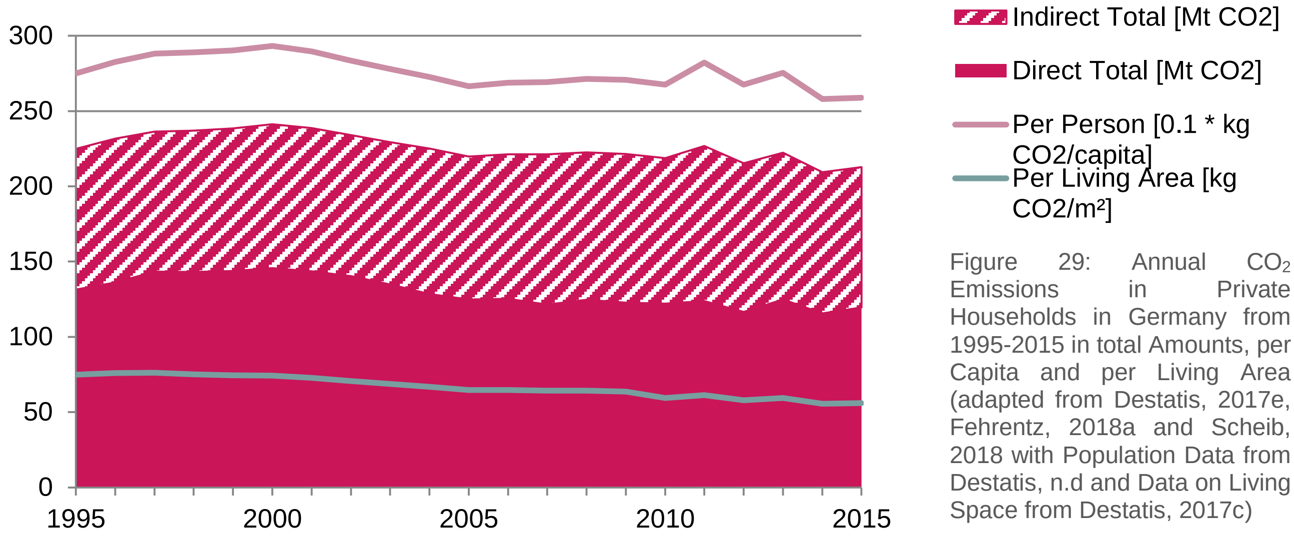

Figure 29: Annual CO_2 Emissions in Private Households in Germany from 1995-2015 in total Amounts, per Capita and per Living Area (adapted from Destatis, 2017e, Fehrentz, 2018a and Scheib, 2018 with Population Data from Destatis, n.d and Data on Living Space from Destatis, 2017c)

Just like energy consumption data, emissions can be expressed in relation to living area and population. The results are presented in Figure 29. The strongest decline can again be seen in emissions per living area. They amounted to 75 kg CO_2/m² in 1995 and decreased to approximately 55 kg CO_2/m² in 2015. Since the amount of living space increased over time, total emissions decreased at a lower rate.

Emissions per capita have developed similarly to total emissions, because changes in population were rather small. Emissions per capita were highest in the year 2000, when they reached nearly 3 t per person. In 2015, emissions per capita within the household sector were still above 2.5 t. In comparison with global goals (cf. Figure 13), the amounts are not only very high, but they also do not show an adequate decrease. By 2050 emissions per person of all sectors combined need to be at below 2.6 t. Currently, following the consumption-based approach, this amount is taken up by emissions in private households alone. The production-based approach would bring more positive results for Germany, but would also assign responsibilities to producers instead of consumers. The focus on consumption-based emissions should boast the liability of residents in Germany. Strong efforts are needed to reduce emissions per capita according to global mitigation goals.

3.4.2 By Applications

Similar to the break down of energy use, direct and indirect emissions per capita within the private household sector can be split further into applications. The different types of application were presented in section 3.3.3 already and are used here again.

The results are presented in Figure 30. Direct emissions mainly take place in space heating and the generation of hot water, while indirect emissions occur in all applications.

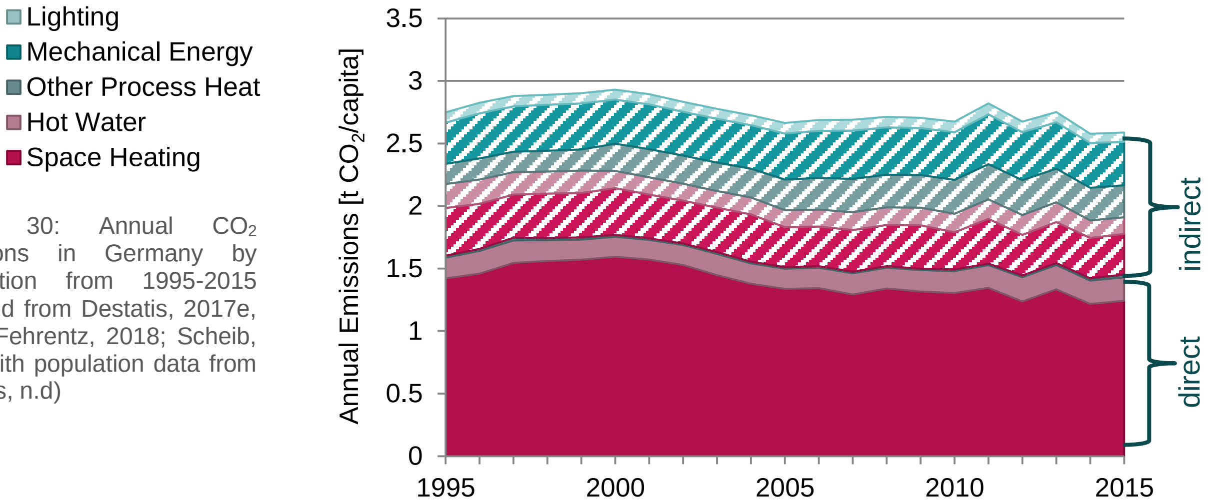

Figure 30: Annual CO_2 Emissions in Germany by Application from 1995-2015 (adapted from Destatis, 2017e, p. 50; Fehrentz, 2018; Scheib, 2018 with population data from Destatis, n.d)

When looking at the application, it is clear that space heating has the largest climatic impact. However, its share is lower in CO_2 emissions than in energy use, which means that its emission factor is below average. Emission factors can be calculated by dividing CO_2 emissions by energy use. They are visualized in Figure 31. It can clearly be seen that CO_2 emission factors of heat are much lower than the ones mainly generated by electricity. A unit of heat energy emits only approximately 300 g CO_2, while the same unit of electricity emits over 500 g CO_2. Heating still has such an important meaning, because the amount of energy consumption is much higher (cf. section 3.3.3).

The calculated emission factor of lighting shows very similar changes since 2010 to the changes of total emissions in the residential building sector (cf. Figure 30 and Figure 31). Developments of rise and decline from 2010 to 2015 are too strong to only be explained by changes in technical equipment. The decline from 2011 to 2012 took place in all applications with electricity as main energy source. It can be assumed, that the emission factor of electricity has decreased because of a change towards renewable energy sources. From 2012 to 2013 however, lighting shows a strong increase in its emission factor, which does not occur in other applications with electricity as main energy source. This observation remains unexplained.

Despite the fact that the factor for applications relying on electricity has a larger variety, all factors are rather constant over time. This observation might at first sight be surprising for space heating, since in its composition oil has decreased while renewable energy sources have increased (cf. section 3.3.5). However, the main source within renewable energy sources was untreated wood, of which the emission factor was assumed at 368 g CO_2/kWh (Fehrentz, 2018c; UBA, 2018). An increase of renewable energy sources did therefore not lead to a decrease of emissions per energy unit, but contrarily to a slight increase.

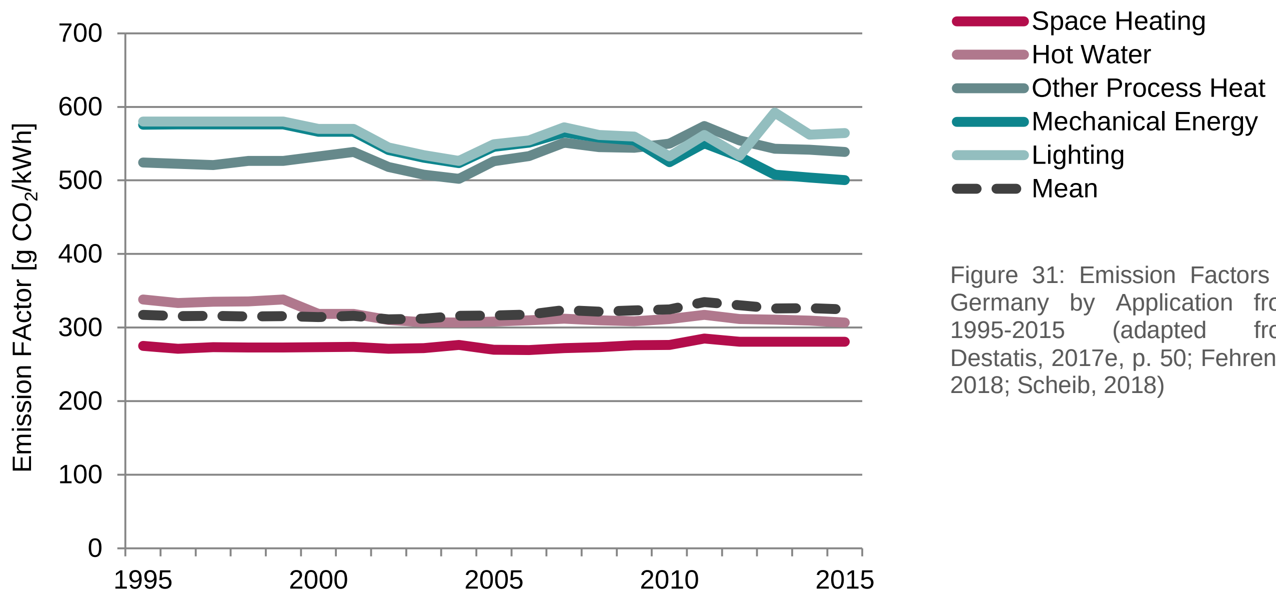

Figure 31: Emission Factors in Germany by Application from 1995-2015 (adapted from Destatis, 2017e, p. 50; Fehrentz, 2018; Scheib, 2018)

The overall mean emission factor for all energy use in private households also shows a slight increase. It is much lower than emission factors for other process heat, mechanical energy and lighting, because the share of these applications in total energy use is less than 20 % (cf. Figure 24). The visualization in Figure 31 makes clear that according to the approach by the Federal Statistical Office trends in emission per generated energy do not show desired effects of emission reduction per generated energy unit.

3.4.3 By Source for Electricity

The emission factor of electricity logically depends on the composition of sources. The national electricity mix from 2015 is shown in Figure 26. Energy sources are divided into conventional and renewable energy sources.

Direct CO_2 emission factors of conventional and renewable energy sources as used in the German NIR are provided by the UBA (2018). In a different publication, the UBA complemented these factors with other GHG and indirect emissions (Memmler et al., 2017, p. 43). Surprisingly, direct emission factors of CO_2e are very similar to the ones which only refer to CO_2 as the only GHG (ibid., p. 43). Emissions for the generation of electricity therefore seem to mostly consist of CO_2. Comparisons between both units are still not ideal, but possible due to the only minor differences. Also, when emission factors are available for only CO_2, they still represent most of all GHG emissions.

Also, the authors of this extended study included indirect emissions (Memmler et al., 2017, p. 43). The resulting emission factors refer to fuel input. Fuel utilization rates in 2015 ranged from 35 % for lignite to 51 % for gas (Icha & Kuhs, 2017, p. 16; Memmler et al., 2017, p. 42). When both are combined, emission factors refer to electricity use (Icha & Kuhs, 2017, p. 16). The results are shown in Figure 32.

It is important to note that utilization rates change over time. The average utilization rate was only 37 % in 1990 and increased to 47 % in 2015 (ibid., p. 17). Emission factors referring to final energy use are consequently not fixed, but have improved over time. It can be assumed, that the factors will continue to improve in the future.

Additionally, it should be noted that nuclear energy emits only very little GHG. However, due to other environmental risks and the decision of the federal government to phase out of nuclear energy by 2022 (Deutscher Bundestag, 2011, p. 7), it will not be included as prospective energy source in this paper and is therefore excluded from the visualization in Figure 32.

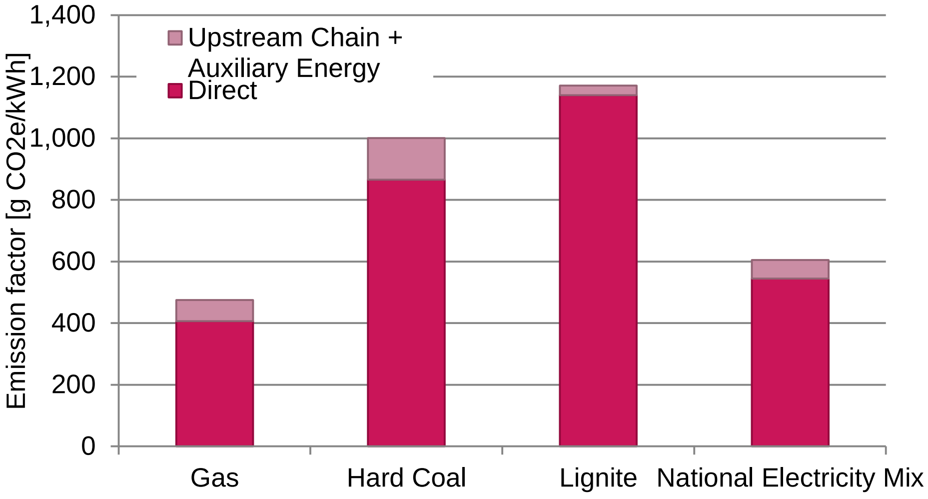

Figure 32: CO_2e Emission Factors for Conventional Energy Sources of Electricity in Germany in 2016, including Fuel Utilization Rates (calculated by combining CO_2e Factors from Memmler et al., 2017, p.43 with Fuel Utilization Rates from Icha & Kuhs, 2017, p. 16) and the National Electricity Mix (adapted from Memmler et al., 2017, p. 80)

Emission factors for conventional energy sources range from over 400 g CO_2e/kWh for gas to nearly 1,200 g CO_2e/kWh for lignite (cf. Figure 32). The emission factor of the national electricity mix was 605 g CO_2/kWh in 2016 (Memmler et al., 2017, p. 80). From 1990 to 2015 it has decreased by 30 % (cf. Icha & Kuhs, 2017, pp. 10, 16). Such a decrease could not be seen in the data published by the Federal Statistical Office (cf. Destatis, 2017e; cf. Figure 31), which can be traced back to the different accounting methods of indirect emissions. The decrease of 30 % is mainly caused by the increase in renewable energy sources, of which most are assumed to contribute with zero direct emissions (Tietje, 2018; UBA, 2018). The emission factor for the national electricity mix (cf. Figure 26) therefore only expresses direct emissions and is mostly based on gas, hard coal and lignite alone.

While the local energy mix for electricity is usually assumed to be the same as the national one (Tietje, 2018), the emission factor for electricity can slightly be adjusted to local conditions. Based on a calculation conducted by the Länderarbeitskreis Energiebilanzen (LAK), the emission factor for electricity in Hamburg can be adjusted to 634 g CO_2/kWh[I] (LAK, 2018). The adjustment made by the statistical office for Hamburg and Schleswig-Holstein (called Statistikamt Nord) is much smaller. The Statistikamt Nord published an energy and CO_2 accounting paper with a slightly lower factor of 539 g CO_2/kWh[II] (Tietje & Teunis, 2018b, pp. 10-15). Since the latter is used in local statistics, it will also be used in this paper.

In Hamburg the emission factor for electricity was 539 g CO_2/kWh in 2015.

Despite past reductions, the long-term emission goal imposes great efforts. By 2050 the CO_2 emission factor for electricity is supposed to be less than 80 g CO_2/kWh with a primary energy factor of 0.44 (Bürger et al., 2016, p. 157). Consequently, the share of renewable energy sources needs to increase further.

Even though in the electricity mix most renewable energy sources are assumed not to emit any GHG, in reality they emit additional amounts of indirect GHG. The emission factors depend on the source on one hand, and on the used technology on the other hand. Figure 33 presents the different emission factors categorized by source. The emission factors range from nearly zero to 200 g CO_2e/kWh. Sources such as the use of waste, wind, hydropower, liquid biomass, photovoltaics and geothermics do not emit any GHG during operation. They only have indirect emissions, which in the case of geothermics can still lead to an emission factor of 200 g CO_2e/kWh. Other sources, such as solid biomass, landfill and sewer gas as well as biogas and biomethane also have direct emissions.

[I] The emission factor for electricity in Hamburg in 2015 given by the LAK is 176 kg CO_2/GJ, which equals 634 g CO_2/kWh.

[II] The “Generalfaktor Strom” for Hamburg in 2015 was 149.71 kg CO_2/GJ and equals 539 g CO_2/kWh.

These direct emissions are even higher in the statistics given by the UBA for the NIR (2018). Since indirect emissions of renewable energy sources do not play a role in the electricity mix, statistically they can be ignored. Still, it should be clear to planners and policy makers, that in reality the generation of electricity with renewable energy sources nonetheless involves more GHG emission than usually expressed by emission factors.

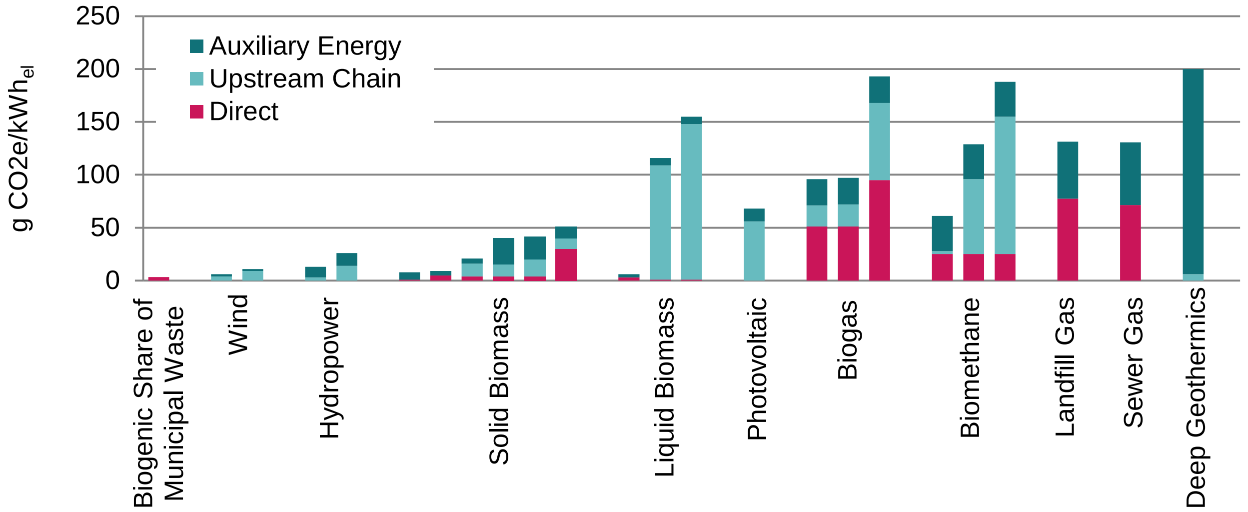

Figure 33: CO_2e Emission Factors for Renewable Energy Sources of Electricity in in Germany 2016, including Fuel Utilization Rates (Memmler et al., 2017, pp. 45-78)

3.4.4 By Source for Heat Energy

The extended study conducted by the UBA also gives CO_2e factors for direct and indirect emissions resulting from the energy supply for heat energy (Memmler et al., 2017). As shown in the study, the difference between CO_2e and CO_2 emissions is diminishingly small (ibid., p. 80). Data quantifying only CO_2 emissions such as UBA (2018) is consequently still very representative for total GHG emissions.

The given factors refer to final energy use but include all emissions from primary to net energy. Fuel utilization rates highly depend on the technology used. Cogeneration plants for example reach high efficiencies when they generate heat and electricity at the same time. They reduce the total emission factor by over 30 % (Fritsche & Rausch, 2008, pp. 14, 15). The values used are mean values of different technologies (Memmler et al., 2017, p. 79).

CO_2e emission factors divided by their fuel utilization rate are shown in Figure 34. Conventional sources of heat energy emitted approximately 300 g CO_2e to 600 g CO_2e per kWh of final energy in Germany in 2016. In comparison with the factors for electricity (cf. Figure 32), the factors are smaller. Gas for example had an emission factor of more than 470 g CO_2e/kWh for electricity and is only approximately 300 g CO_2e/kWh for heat. The reason for the difference lies in the utilization rates. It was only 51 % for electricity use (Icha & Kuhs, 2017, p. 16), but 88 % for heat energy (Memmler et al., 2017, p. 79). Utilization rates are close to 100 % for heat supply by district heat and electricity (ibid., p. 79). Still, their emission factors include losses during conversion prior to the delivery to private households.

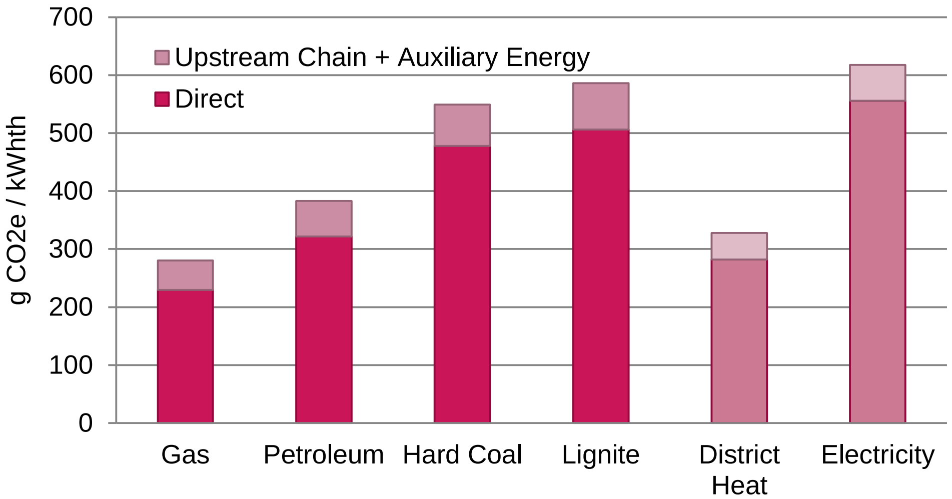

Figure 34: CO_2e Emission Factors for Conventional Sources of Heat Energy and for District Heat and Electricity in 2016, including Fuel Utilization Rates (adapted from Memmler et al., 2017, pp. 79, 80)

Due to its high emission factor, electricity as energy source for heating is generally less preferable. The share of apartments generating heat from electricity is rather low anyway (cf. section 4.6.1). Since data on electricity used in residential buildings for heating was not available for the case study (cf. Appendix H), electricity used for the purpose of heating cannot be specified in the case study. The potential of using a possibly existing surplus of electricity should however not be underestimated and will be taken up later on.

Because of uncertainties in the utilization rate during conversion, the emission factor for district heat is not easy to determine. Energy sources are converted to heat energy and then delivered to private households. As shown before, cogeneration has a high efficiency and can therefore reduce the emission factor. In addition to the technology used, emissions of district heat highly depend on the energy source mix it is provided with. As shown in Figure 34, the national factor is approximately 300 g CO_2e/kWh.

In Hamburg the direct emission factor for district heat was <u>314 g CO_2/kWh</u> in 2015.

For district heat in Hamburg specifically, the LAK calculated a factor of 212 g CO_2/kWh[I] (LAK, 2018), while Statistikamt Nord calculated a factor of 314 g CO_2/kWh[II] (Tietje & Teunis, 2018b). Both used emission data given by the UBA (2018) in their calculation and therefore only refer to direct emissions (Tietje, 2018). The great range of estimates demonstrates the uncertainties included in such calculations. Again, the latter is chosen for the case study in chapter 4, because it is used in local statistics. The associated energy mix was shown in Figure 26. The factor refers to CO_2 alone, but as the comparison of amounts in CO_2 and CO_2e show, the amount of CO_2e would only be diminishingly higher (such as Memmer et al., 2017 and UBA, 2018).

A comparison of emission factors for district heat and gas as heat energy source shows that district heat per se is not more environmentally friendly. By contrast, currently the use of district heat emits more GHG than the use of gas. The reason why often planners aim at an expansion of the district heating grid, is that district heat contains a great potential of becoming less carbon intense. The national long-term goal for district heat is an emission factor of 90 g CO_2/kWh with a primary energy factor of 0.50 in 2050 (Bürger et al., 2016, p. 157). District heat would then emit far less CO_2 per generated energy unit than any conventional energy source. To reach this goal, the national mean factor therefore needs to be cut by two thirds.

[I] The emission factor for district heat in Hamburg in 2015 is given at 59 kg CO_2/GJ, which equals 212 g CO_2/kWh

[II] 87 kg CO_2/GJ = 314 g CO_2/kWh

Again, the importance of including emission from the upstream chain and from auxiliary energy can be seen when looking at renewable energy sources. While direct emissions mostly stay below 50 g CO_2e/kWh, the total can excess 100 g CO_2e/kWh (cf. Figure 35). The range from nearly no emissions for the use of municipal waste to 200 g CO_2e/kWh for environmental heat makes clear that within renewable energy sources a differentiation of sources is needed to quantify exact emission. Nevertheless, according to this approach the emissions per kWh of all technologies stay below the ones from conventional sources. This would generally confirm the fact that the usage of renewable energy sources reduces the climatic impact.

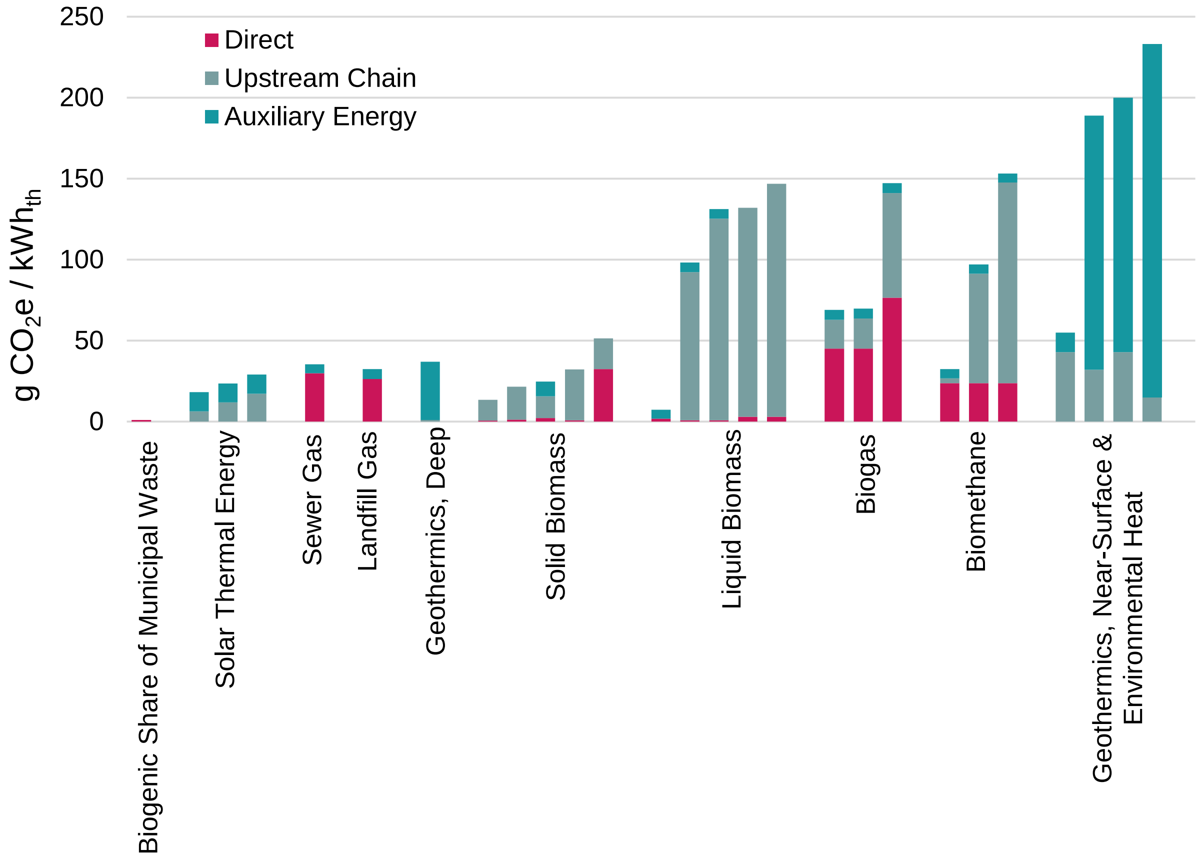

Figure 35: CO_2e Emission Factors for Renewable Sources of Heat Energy in 2016, including Fuel Utilization Rates (adapted from Memmler et al., 2017, pp. 83-121)

A more differentiated picture on the climatic impact of renewable energy sources is drawn by emission factors provided by the UBA (2018). They include the actual direct emissions resulting from materials such as wood and gas, while factors given in Figure 35 do not present emissions, which were contained in the material and set free through combustion (Fehrentz, 2018c). These different approaches exhibit a major difficulty in emission accounting. When all actual direct emissions are taken into account, emission factors of renewable energy sources can be higher than those of conventional energy sources. In the case of firewood, the approach used in Figure 35 assumes that GHG emitted during combustion are simply given back to the atmosphere, from were the tree has absorbed them. Since wood is a renewable raw material, newly growing trees can take up emitted amounts. Contrarily, the approach represented by factors given by the UBA (2018) registers all GHG taking place during combustion, no matter if they result from the burning of renewable or conventional energy sources. This leads to a factor of nearly 370 g CO_2/kWh (UBA, 2018), which is even above the factor for petroleum (cf. Figure 34). It was the reason why in the publications of the Federal Statistical Office the overall emission factor has risen despite the increase in the share of renewable energy sources (cf. section 3.4.2; Fehrentz, 2018c). In consequence, the considered approach needs to be understood first, before existing developments in GHG emission are evaluated.

3.4.5 Influencing Factors on Carbon Intensity

Carbon intensity expresses the amount of emissions per energy unit. It was presented in the preceding chapters by emission factors. Carbon intensity represents the second component of emission reduction besides energy saving. When the amounts of energy use stay constant, emissions can still be reduced by improving the emission factor.

The emission factor depends on two factors: the energy source and the utilization rate. Different energy sources emit different amounts of GHG per generated energy unit. These factors are published by the UBA (2018) and are further used by other statistical authorities. An emission reduction can be achieved by switching to an energy source with a smaller emission factor. Emission factors are highest for hard coal and lignite, which is why a switch from coal to any other energy source usually results in emission reduction. The switch can take place on-grid, which implies a change of fuel in larger plants. But the change can also happen in an off-grid solution, when for example photovoltaic panels or pipes for solar thermal energy are installed on top of the roof of a residential building.

However, statistics highly depend on methods of calculation. When renewable energy sources are assumed to have zero emissions, their use improves resulting emission reductions immensely. Contrary, when their actual emissions during combustion of wood for example are included in the calculation, emission factors can even be higher than that of conventional energy sources.

The second factor concerns utilization rate. In final energy the utilization rate is mostly important when the energy source has already been converted to electricity or heat. Regarding electricity, it has improved constantly from 37 % to 47 % within 25 years (cf. section 3.4.3). For heat the most important technology is cogeneration, which can decrease fuel input by 30 % (cf. section 3.4.4). Higher utilization rates during the conversion from primary to final energy decrease primary energy use and thereby emission factors of final energy use.

When final energy is delivered to a household in the form of gas, oil, pellets, or other materials, it is converted to heat or electricity in the residential building. Here, the efficiency degree of condensing boilers and other technological equipment come into play. However, since these are located in private households, it is usually more difficult to access this last step of conversion.

Summing up, carbon intensity is reduced when efficiency is high and losses are low. In addition, less carbon intense energy sources should be used. These are mostly renewable energy sources, while the most carbon intense energy sources are hard coal and lignite.

3.5 Savings Strategies

Previous data have shown that total amounts of final energy use and CO_2 emissions have decreased only marginally, which mean that despite an increase in the share of renewable energy sources the average CO_2 emission factor was approximately constant. Energy use and emission per capita did also only decrease by very little. The only significantly positive development was energy use and CO_2 emissions per floor area, which decreased by a fourth. However, the increase of living space from 1995 to 2015 was so high that total energy and emission savings are negligible. How can emissions decrease more rapidly in the future?

As indicated before, there are two rooms for manoeuvre to limit the climatic impact of residential buildings during their operational phase:

- **a)** Reducing final energy use by increasing energy efficiency, and
- **b)** Reducing carbon intensity by decreasing emissions per generated energy unit.

Both strategies have to work together to reach the national goal of a nearly zero energy building stock by 2050 (cf. section 3.1.3). In scenarios with restrained energy reduction the share of less carbon intense sources in the energy mix needs to be higher, whereas large energy savings allow a higher share of conventional, more carbon intense energy sources (BMWi, 2014a, p. 10; Bürger et al., 2016, p. 174). The extreme scenarios of a maximal reduction in final energy use as well as a maximal share of renewable energy sources with simultaneous changes in the other component are shown in Table 2. Future developments have to be located in between these two extreme scenarios to achieve a nearly zero energy builing stock by 2050 and a reduction of CO_2 emissions relative to 2008 of over 80 % (ibid., p. 56).

Year	Final Energy Use per Living Area		Share of Renewable Energy Sources in Total Final Energy Use	
2008	185 kWh/m²	100 %	9 %	100 %
2050	104 kWh/m²	- 44 %	50 %	+ 265 % (max)
2050	74 kWh/m² (Effizienzhaus 55)	- 60 % (max)	34 %	+ 74 %

Table 2: Ways to reach an 80 % Reduction in Primary Energy Use in Buildings in Germany by 2050 relative to 2008 (adapted from BMWi, 2015, pp. 47-56)

The following sections will look at existing strategies to reach a reduction in final energy use and an increase in the share of renewable energy sources as well as available instruments for policy makers.

3.5.1 Energy Efficiency

According to the German Chancellor Angela Merkel, there is no way around a significant efficiency enhancement in the building sector. Since new buildings have to follow strict regulations on energy efficiency already, tackling the energy use of the building stock is of high importance (Merkel, 2017).

Most energy is used for space heating (cf. 3.3.3), which is why a major contribution is the reduction of heat energy losses, which can be achieved by the retrofit of buildings. The UBA conducted a case study in a suburban municipality in the south-west of Germany with mostly residential buildings erected between 1984 and 1994. The researchers found that 20-60 % of annual GHG emissions could be reduced if all buildings were refurbished according to the standard of EnEV 2009, and 60-80 % if the new standard was that of a passive-house (Schuberth & Tschetschorke, 2012, p. 82). Retrofitting is the most important adjustment method to achieve a nearly zero emission building stock in Germany (Bürger et al., 2016, p. 208). Until 2008 approximately 40 million square metres of thermal insulation systems were installed annually (UBA, 2011, p. 98). To reach a nearly climate neutral building stock however, the renovation rate has to double (Deutsche Bundesregierung, 2010, p. 2).

Regarding the design of energetic rehabilitations, different approaches are possible. On the one hand, the development of fixed retrofitting measures for certain building types would help increasing the renovation rate (Bürger et al., 2016, p. 208; Gottschick, 2018). On the other hand, individually coordinated retrofitting measures are more effective and therefore should be supported as well (BMWi, 2015, pp. 72, 73).

A large impact can be achieved by the adjustment of existing technologies. According to Manuel Gottschick from OCF Consulting in Hamburg, major contributions could be achieved, if the hot water supply was adjusted to work more efficiently (2018). With simple saving measures such as the adjustment of water temperatures, every type of household could save 40 % of electricity use (Weyland et al., 2015, p. 27).

When it comes to the efficiency of electric devices, new ones usually achieve better results. A freezer with the energy label “A++” for example uses 60 % less electricity than a similar freezer of 10 years age (UBA, 2011, p. 76). The energy demand for lightning could be reduced by 14 % if LEDs were put into place (IEA, 2017, p. 46). An exchange of old devices therefore involves great energy saving potential at the individual level. However, the effect is decreased when embodied energies and the level of equipment are taken into account. Also, improvements in energy efficiency can lead to a rebound effect, which means that energy demand increases (IEA, 2017, p. 48; Weyland et al., 2015, p. 14). Consequently, an improvement of energy efficiency does not automatically lead to a decrease of total amounts of electricity use (Weyland et al., 2015, p. 14). Instead of efficiency, the UBA therefore pleads for sufficiency, which aims for a reduction of demand for goods and services (ibid., p. 15).

As shown, the main focus is on building retrofits to achieve set targets of energy efficiency in the residential building sector. The replacement of less efficient devices can involve certain throwbacks, which is why here sufficiency can be more important than efficiency.

3.5.2 Carbon Intensity

The long-term goal for 2050 is a reduction of the CO_2 emission factor for electricity to 78 g CO_2/kWh and for district heat to 90 g CO_2/kWh (Bürger et al., 2016, p. 157). In order to reach this goal, the share of less carbon intense energy sources and of the fuel utilization rate need to increase.

According to the UBA, "shifting from liquid fuels to solid fuels to gaseous fuels and biomass has brought about considerable CO_2 emissions reductions." (2017b, p. 234). This observation highly depends on the assumed emissions of renewable energy sources. When the combustion of for example firewood is assumed to statistically not emit any GHG, it can be a preferred solution (such as in the case study of Schuberth & Tschetschorke, 2012, pp. 106, 107).

The share of renewable energy sources in final energy use of space heating was already above 15 % in 2015 (cf. section 3.3.5). According to a projection made by the Federal Ministry for Economic Affairs and Energy, this could amount to over 20 % by 2020 (BMWi, 2015, p. 40). In the sector of electricity, the share of renewable sources has to continue to increase to at least 60 % by 2030 (Agora Energiewende, 2017, p. 16).

Regarding district heat, the Fraunhofer Institut counts on decarbonizing these grids. Heat can be generated more efficiently when large plants supply a large number of customers (BMWi, 2015, p. 75). This implies an increased number of buildings being connected to the grid and the construction of additional pipes. By 2050 more than 20 % of all energy demand in buildings should be covered by heat grids (Agora Energiewende, 2017, p. 10).

Prefered energy sources for district heat are large solar thermal, deep geothermics and the use of industrial waste heat (Agora Energiewende, 2017, p. 75). Since these technologies do not reach very high flow temperatures, the temperature of the grids needs to be rather low. More incentives are needed to implement low-temperature heating grids at larger levels (BMWi, 2015, p. 75). There are companies, such as Exergene® from Hamburg[I], which specialize in obtaining hygiene standards at low temperatures.

A municipality has more room to act when it owns the heat grid. The repurchase of Hamburg's energy grids, which was decided in a referendum in 2013 (hamburg.de, 2013), will consequently help to enhance the potential of expanding and decarbonizing heat grids. Different scenarios were developed to replace coal in the generation of heat energy in Hamburg (BUE, 2017b). The planned phase-out of coal as energy source for the generation of heat as demanded by the public initiative "Tschüss Kohle" (in English: Bye coal) conflicts with plans to use heat generated by the coal-fired power plant Moorburg (BUND, 2018; Dey, 2018). This conflict still needs to be solved.

When residential buildings are not connected to district heat, a technology change can still lead to higher fuel utilization rates and consequently to lower emission factors. Heat pumps for example can offer a better efficiency, but lead to a higher electricity demand (Agora Energiewende, 2017, p. 75). In Germany the share of more efficient boilers has constantly increased (UBA, 2011, pp. 95-97).

An increase in electricity demand however is not automatically an adverse effect. Electricity has such a great potential to decarbonize, that in the future it might be desirable to increase its use for heating (Agora Energiewende, 2017, p. 34). "Expanding the use of electricity" (Sugiyama, 2012, p. 464) can be called electrification. Several models assign a high future electrification rate to the building sector (BMWi, 2015, p. 52; Sugiyama, 2012, p. 467). However, for an actual endeavour of electrification a very realistic plan for the decarbonisation of the electricity mix is needed.

In order to react to peaks in demand, flexibility and a "Smart Market" are needed (Agora Energiewende, 2017, p. 78; BDEW, 2017, p. 25). The start-up "Enyway" in Hamburg is an example of innovative restructuring of the energy market. Every person that generates energy from renewable sources can sell it directly to the end user[II]. Smart Markets can be complemented by so-called Smart Homes (cf. BMWi, 2015, pp. 79, 80). The operation and heating of an apartment can be optimized when electric and heating devices are managed according to the presence of inhabitants and existing energy surpluses or shortages.

To increase flexibility further, new technologies such as Power-to-Heat and Power-to-Gas, where Electricity is converted to heat or gas, are coming up. They represent an opportunity to store energy when generated electricity is not needed right away. Their efficiency is rather low, but nonetheless they offer a solution to the issue of peaks

[I] More information at https://www.exergene.de

[II] More information at https://www.enyway.com and lows in electricity generation and demand (Agora Energiewende, 2017, p. 44; BDEW, 2017, pp. 12-22).

Generally, the necessity to use more renewable and less conventional energy sources is clear. In heat supply the focus often is at the expansion of district heating grids, even though currently their emission factors are rather high (cf. section 3.4.4). Defining specific targets and implementing new technologies is certainly challenging. This is why available instruments and their effect are important to be aware of and to use.

3.5.3 Instruments

There are several ways to reach goals of energy efficiency and carbon intensity. This chapter will give a brief overview of different approaches. Due to the scope of this paper, the explanations will not go very far into detail. Generally, an Authority can choose between a set of instruments, which can be categorized as follows (IPCC, 2014a, p. 108):

a) Economic Instruments,
   which imply taxes on carbon and energy, tradable certificates for energy efficiency improvements, subsidies for energy audits and fiscal incentives for fuel switching.
b) Regulatory Approaches
   on energy efficiency standards for buildings and equipment and voluntary labelling
c) Information Programmes
   regarding energy audits and advice as well as levelling programmes.

Several measures were implemented already. In Germany, retrofitting measures of apartments and the integration of renewable energy sources are subsidised through funding programmes of the national development bank KfW[I] (BMWi, 2014b, pp. 13, 14). These are complemented by other financial programmes at the level of states[II].

The most important regulation regarding energy use in residential buildings in Germany is the so-called Energieeinsparverordnung (EnEV, in English Energy Saving Regulations) (BMWi, 2014b, p. 14). New residential buildings have to follow standards set by appendix 1, EnEV. Some provisions also refer to the existing building stock (§10 EnEV). When parts of a building are changed, the modernisation has to comply with certain energy standards defined in appendix 3, EnEV. However, currently there is no need to perform retrofitting measures as long as no modernisation measure is carried out. This is why in a

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[I] To be found at: https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestandsimmobilie/Förderprodukte/Förderprodukte-für-Bestandsimmobilien.html

[II] Such as the IFB Hamburg: https://www.ifbhh.de/umwelt/modernisierung-von-wohngebaeuden/

case study in Toronto, ambitious building codes were not sufficient, but deep retrofits were necessary (Mohareb & Kennedy, 2014, p. 691). Standards and regulations in Germany lack the obligation to perform rehabilitations.

Introducing the obligation to rehabilitations in regulatory law would have the greatest effect on energy and GHG saving, in particular to reach private actors. As the economy of scale sets in, costs would reduce and standardized retrofitting measures would be created (Gottschick, 2018). However, the Federal Government counts on economic incentives instead of compulsions (Deutsche Bundesregierung, 2010, p. 3).

At the level of states Hamburg had introduced its own climate protection regulation with energety standards of residential buildings in 2007 (§2 HmbKlischVO), which were already overtaken by the EnEV of 2009 (Hermelink, 2010, p. 25). The public initiative "Tschüss Kohle" targets a change of the regulation. According to its proposal, the global 1.5°C target and the phase-out of coal use should be included in the regulation (NaturFreunde Hamburg, 2018).

Experiences are exchanged through international programmes such as "The Covenant of Mayors for Climate & Energy"[I] and the "Urban Transition Alliance"[II]. Another example for the informative and informal approach is the development of climate protection plans. Defined goals and set measures are not binding, but can help to inform the public and policy makers of the current situation as well as future road maps. As shown in section 2.5.4, Hamburg has introduced several plans over the years with the latest one published in 2015. Climate protection plans can also be developed at the level of municipalities. In 2018, Altona will publish its climate protection plan as second borough in Hamburg after Bergedorf (cf. Bürgerschaft der FHH, 2015, p. 17; Gottschick et al., 2016).

All types of instruments offer a great variety of measures, which cannot be explained here in further detail. It is important to know about existing regulations and programmes at different levels to decide where action is needed. Additionally, the effectiveness of different measures should be assessed before making a decision.

[I] More information at https://www.covenantofmayors.eu/

[II] More information at https://urbantransitions.org/

3.6 Open Questions

Most policy makers share the understanding of the general goal to intensify efforts of reductions in energy use and GHG emissions. Existing studies have shown how technical upgrades can improve efficiency and emission factors. However, while the technical setting can determine carbon intensity and reduce losses, total amounts of energy consumption are influenced by various factors. A selection of these influencing factors was presented in section 3.3.6. Efforts to reach better efficiency rates might not lead to desired reductions in total energy use and GHG emissions, when energy consumption in private households does not develop as expected.

The difficulty for policy makers in a municipality is to estimate energy use. Several statistics give approximate estimates of average energy demand, which are calculated with the help of several variables such as building age, building type and inhabitants per household. Yet, these are not the same as actual amounts of consumption. The fact that energy consumption depends on innumerable factors raises several questions:

- What role does the urban setting play with regard to energy consumption? If, for example, a certain density of people or households turned out to be less energy consuming, it would be worth striving for in urban planning.
- How do characteristics of the dwellers impact energy consumption? If for example young people or employed people were to use more energy in private households, they could be a target group for information programmes.
- How much does energy consumption depend on the structural setting? If energy consumption was especially high in certain building types or in buildings erected at a certain time, they would need to be addressed in retrofitting programmes.

Thus, a better understanding of energy consumption is needed firstly, to get an overview of the current situation and existing interdependencies and secondly, to decide on effective measures, so-called low-hanging-fruits. Should these measures address urban setting, inhabitants or buildings? A useful road map for energy saving at the local level requires better knowledge.

The following chapters will analyse the current energy use of residential buildings in Altona and identify parameters which are connected to energy consumption. These parameters concern urban setting, characteristics of residents and structure of residential buildings. The goal is to find interdependencies to enable a better assessment of energy consumption in residential buildings.

4 The Borough Altona

Altona is one of seven boroughs within the city Hamburg. In 2016

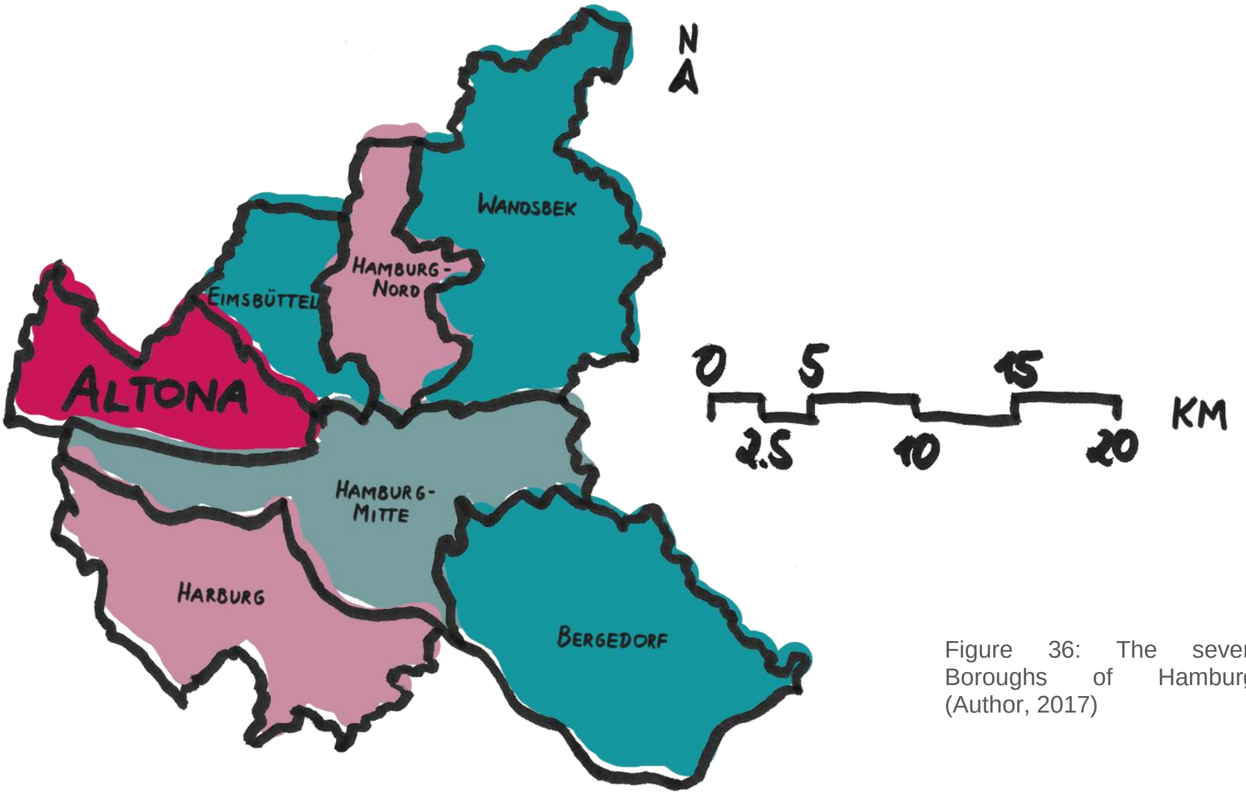


Figure 36: The seven Boroughs of Hamburg (Author, 2017)

Altona received introductory counselling for climate protection (in German: Einstiegsberatung Klimaschutz) by the company ZEBAU GmbH (in the following called ZEBAU). Subsequent, in October 2017 the district Authority commissioned the companies ZEBAU and Averdung Ingenieurgesellschaft mbH (in the following called Averdung) to create a climate protection concept. The topic of climate protection and energy saving therefore is very present in Altona.

Figure 37 names the 14 districts of Altona and outlines the Statistical Areas lying within each district. Since Altona is located in the western part of Hamburg, its western districts are generally more rural areas, while the eastern districts are more urban. The south of Altona is demarcated by the river Elbe. The districts are further divided into so-called “Statistical Areas” (in German: Statistische Gebiete). Altona consists of 131 of these statistical areas. Their shape is slightly modified in the analysis to exclude areas covered by water. This concerns all Statistical Areas which end in the south in the river Elbe. The areas are cut in a way that only land area is included.

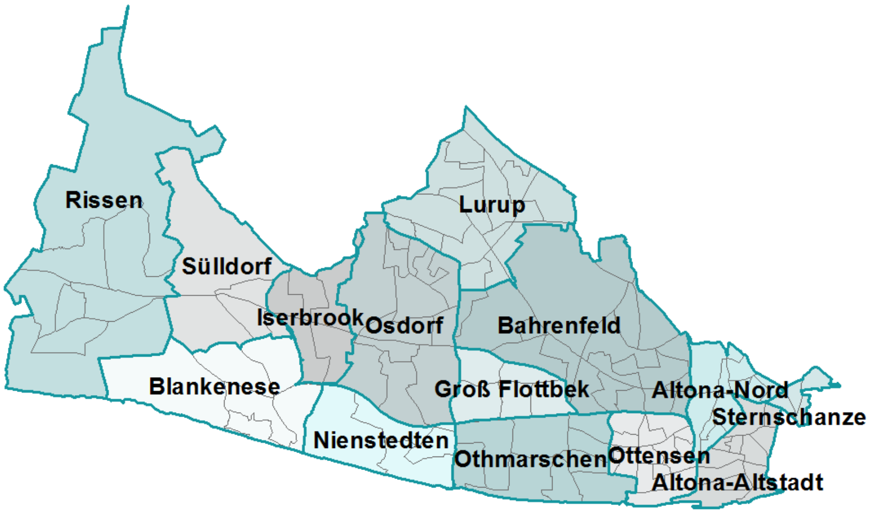


Figure 37: Overview of the 14 Districts in Altona with their Statistical Areas (Author, 2017)

Because of their location, every Statistical Area within the districts shows different characteristics regarding urban setting, residents and residential buildings. In this chapter, the spatial distribution of different variables is visualised in maps. These variables include electricity and heat energy consumption. The visualization will help to outline the characteristics of different parts of Altona, which will be needed in the analysis of energy consumption in chapter 5.

4.1 Source of Data

Due to the availability of data sets, the analysis is made for the year 2015. All data are aggregated at the level of Statistical Areas. The size of the Statistical Areas ranges from 7 hectares in Altona-Altstadt to 682 hectares in Rissen with an average size of 55 hectares. The average number of inhabitants per Statistical Area is just over 2,000. In order for the areas to be representative, four Statistical Areas in Altona-Nord and Bahrenfeld with less than 40 inhabitants or less than 10 residential buildings are excluded of the analysis, reducing the total number of statistical areas to 127. More details on the exclusion of Statistical Areas can be found in Appendix H and Appendix I. The lowest number of inhabitants occurs in a Statistical Area in Bahrenfeld with 46 people living there in 2015.

The source for the geographical data on residential buildings is ALKIS (Amtliches Liegenschaftskatasterinformationssystem, engl.: official real estate cadastre information system). The data was retrieved from the geodatabase called SDP-2016.gdb at Bezirksamt Altona. The selection of residential buildings is explained in Appendix A and shown as black areas in Figure 38. There is very little built-up space in the north-west part of Altona, which is a more rural area. The district Bahrenfeld is partly filled with very few buildings and partly more industrially characterised. The buildings illustrated in Figure 38 are here consequently mostly coloured in dark green. When data from ALKIS was modified or used for calculations, it is explained in the text.

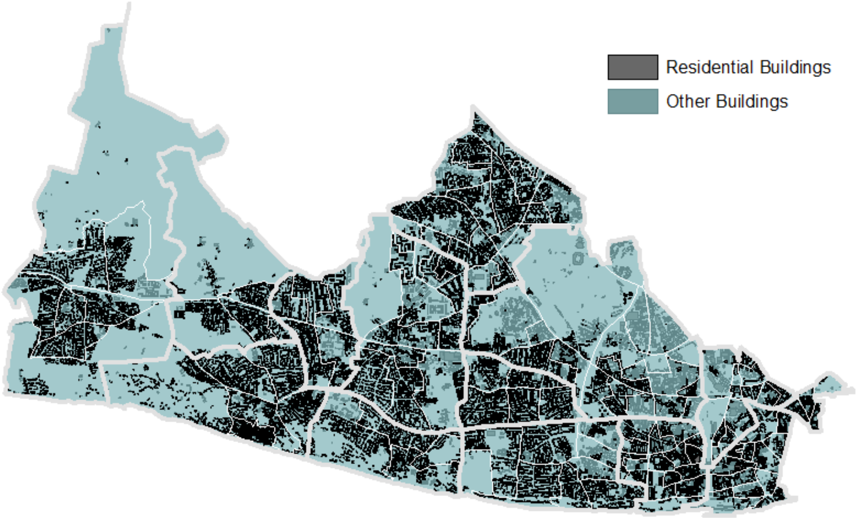


Figure 38: Residential Buildings in the Borough Altona (Author, 2018)

Similar to the district profiles (in German: Stadtteil-Profile), which are published annually by Statistikamt Nord, Bezirksamt Altona is in possession of statistics on social indicators at the level of Statistical Areas. The social indicator table can also be obtained through HafenCity University and were sent to the Author by Frank Rogge (2016). If not noted otherwise, the social indicator table from 2015 is the basis for the indicators presented in the following.

The number of inhabitants was not used from the regular social indicator table, but sent separately by Andreas Kaiser from BSW ("Behörde für Stadtentwicklung und Wohnen"). This is explained in further detail in Appendix E.

Data on building age group and building type was taken from an analysis conducted by the company Ecofys Germany GmbH (in the following called Ecofys), published in 2013. The State Ministry for Urban Development and the Environment (Behörde für Stadtentwicklung und Umwelt, abbreviated BSU) was the customer of the publication. Its title is "Exhaustive survey and mapping of the energetic condition of the building stock in Hamburg" (Hermelink et al., 2013).

Data on energy consumption was provided by the grid operators. Data protection regulations impede the access to consumption data. This is why the person in charge employed by the grid operator and the author of this paper signed confidentiality agreements, which determined the usage of the provided, sensitive data. The consumption data itself cannot be published, but the aggregation at the level of Statistical Areas can be as well as their statistical analysis. The compilation of data on energy consumption in Altona is described in Appendix H and Appendix I.

All data is presented in illustrations, which show the concerning aspect categorized in four levels as filled in areas differentiated by colour. The thresholds of the four levels are mostly determined by quartiles, meaning that all levels represent approximately 25 % of the Statistical Areas. These thresholds were slightly adjusted to have round figures.

4.2 Urbanization

According to the Merriam Webster Online Dictionary, the term "urban" describes the characteristics of a city. Through urbanization an area takes on these city-like characteristics. In this section the term "urbanization" is mostly interpreted as density of different aspects such as inhabitants or households per hectare or building. The illustrations show a very clear picture of more dense, urban parts in the east of Altona. Noticeably, these urban parts have a high density of inhabitants and households per hectare, but a low density in inhabitants per household.

4.2.1 Inhabitants per Household

The average number of people living in a household varies from 1.3 to 2.4. Households located in the eastern part of Altona are closer to Hamburg's city centre. They generally consist of a fewer number of people (cf. Figure 39). Statistical Areas, which were excluded from the analysis, are left blank.

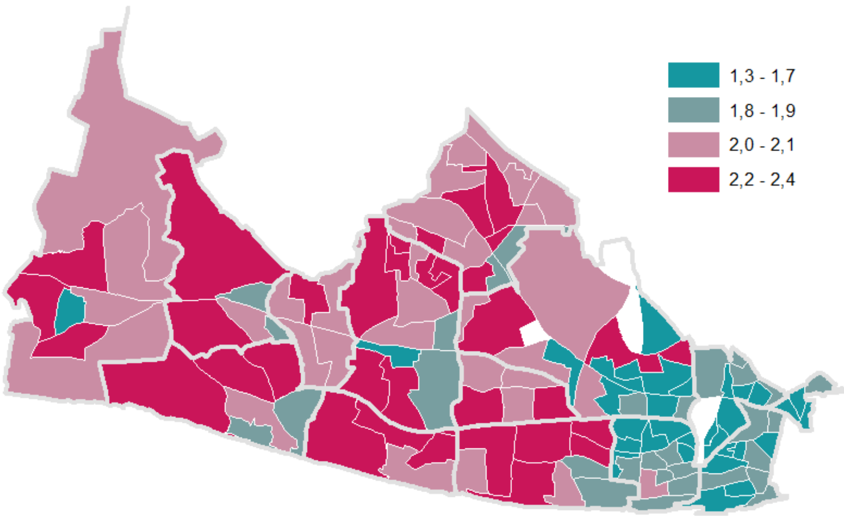


Figure 39: Illustration of Inhabitants per Household in the Statistical Areas of Altona (Author, 2018)

4.2.2 Inhabitants per Hectare

The density of inhabitants per hectare is mostly complementary to the number of people living in a household. Even though in the city centre the number of people per household is low (cf. Figure 39), these are the densest areas with the highest numbers of people per hectare. Consequently, the number of households must be high here (as proven in section 4.2.5).

The density of inhabitants varies immensely from less than 1 to over 300 people per hectare. Apart from the dense areas close to the city centre, an area in the north of Altona also shows high density (cf. Figure 40). It is the neighbourhood called "Osdorfer Born", which is characterised by tall buildings.

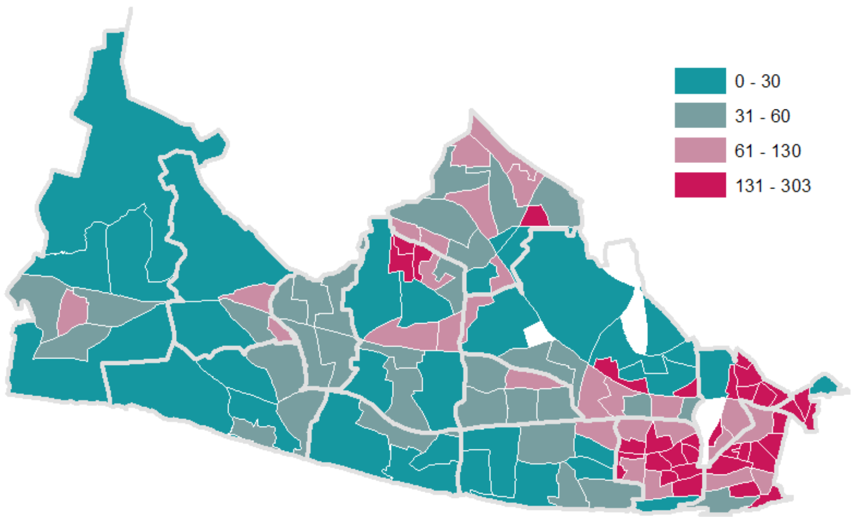


Figure 40: Illustration of Inhabitants per Hectare in the Statistical Areas of Altona (Author, 2018)

4.2.3 Single Person Households

The share of single person households is closely connected to the characteristic "inhabitants per household". The highest shares can consequently be found in the east of Altona. There are a few exceptions. Rissen and Osdorf for example are located further away from the city centre, but have two Statistical areas where the share of single person households is above 60 % (cf. Figure 41).

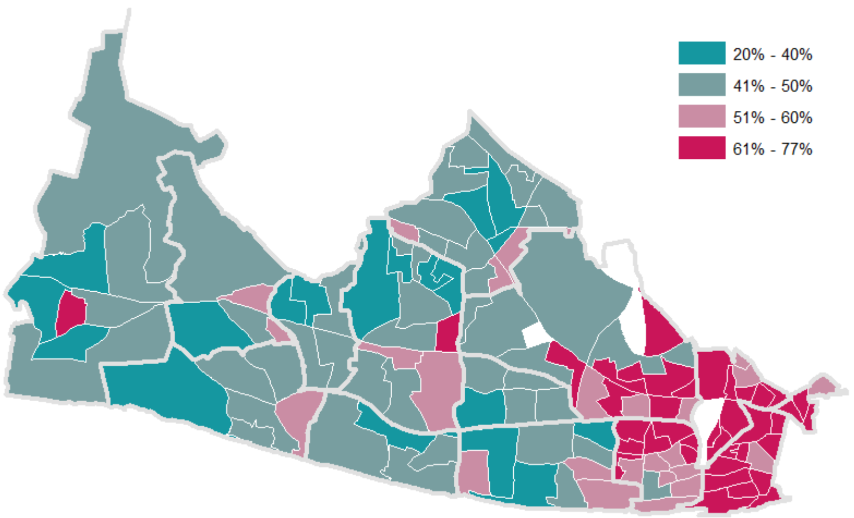
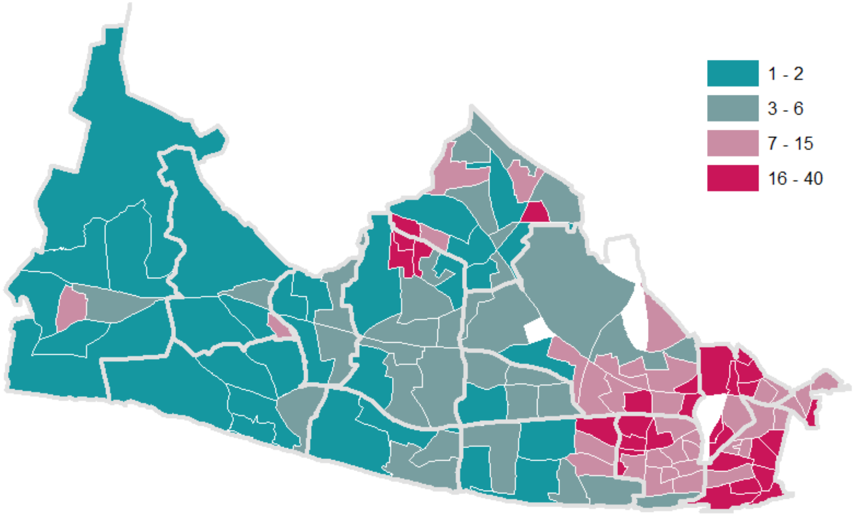


Figure 41: Illustration of the Share of Single Person Households in the Statistical Areas of Altona (Author, 2018)

4.2.4 Households per Building

The number of households per building was calculated based on the social indicator table and residential buildings selected from ALKIS. Uncertainties are therefore involved regarding the selection of residential buildings. Nevertheless, the drawn picture is very clear. In the city centre and in the neighbourhood Osdorfer Born residential buildings include several households. In the more rural and southern areas however, buildings often contain only one or two households (cf. Figure 42).

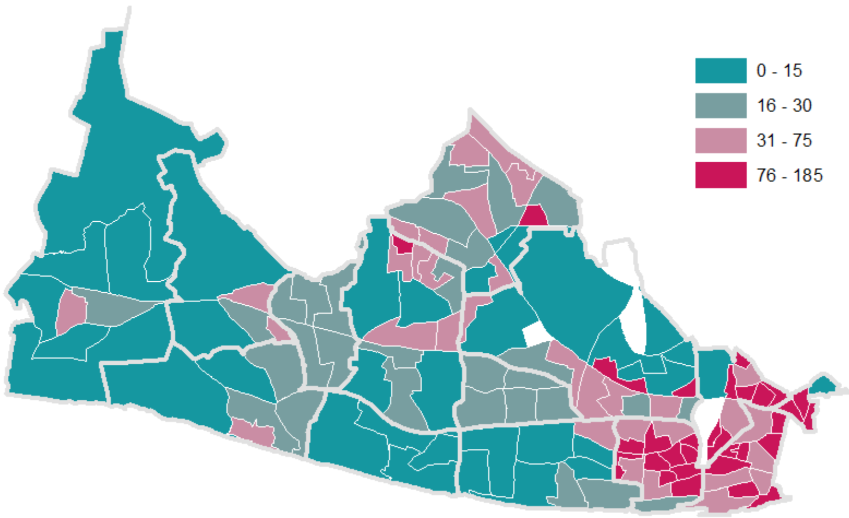
Figure 42: Illustration of the Number of Households per Building in the Statistical Areas of Altona (Author, 2018)



4.2.5 Households per Hectare

Density of households can not only be referred to buildings but to the area. It is a modification of the previous variable, which referred to the building type, while this one also includes the fact of how dense buildings are located. The illustration of households per hectare is similar to inhabitants per hectare (cf. section 4.2.2), showing high densities in areas in the city centre and in the north of Altona (cf. Figure 43).

Figure 43: Illustration of the Number of Households per Hectare in the Statistical Areas of Altona (Author, 2018)



4.2.6 Gross Floor Area per Total Area

In order to grasp the density of built up residential space, the gross floor area (GFA) of residential buildings is calculated by multiplying the ground floor area by the number of full storeys. (For further details on full storeys cf. chapter 4.4.2.) Clearly, the number is only an estimation which is influenced by the uncertainties of the definition of residential buildings and specifications made in ALKIS.

The calculated GFA is then divided by the total area of the district to receive a ratio between built up residential space and the size of the entire area. In very dense areas, the built up gross floor area can be larger than the ground area of the district, which leads to values above 100%.

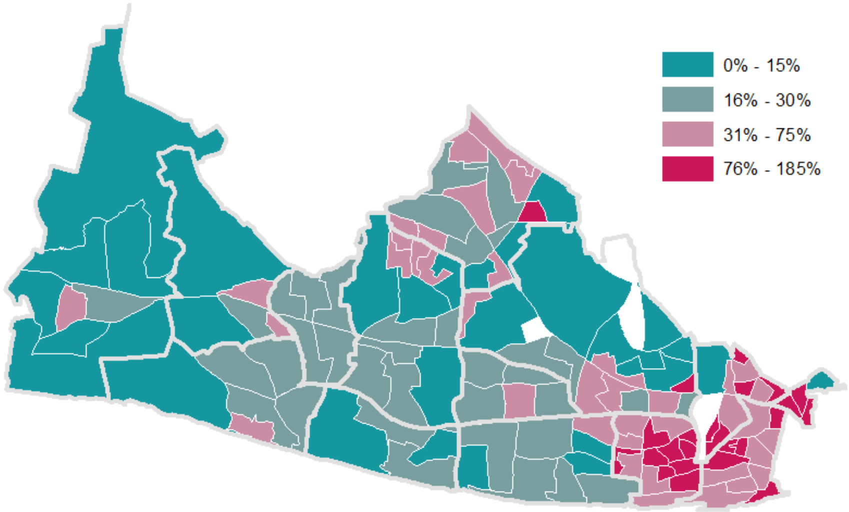


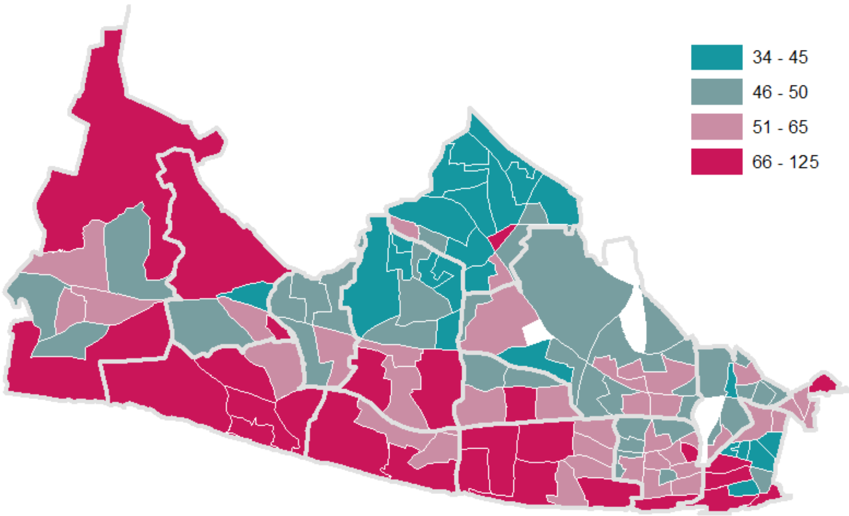
Figure 44: Illustration of the GFA per Total Area in the Statistical Areas of Altona (Author, 2018)

As previous illustrations have suggested, Figure 44 shows that the density of built up residential space is much higher in the eastern and more central areas of Altona. But some other areas, such as Osdorfer Born, also have a very high built up area. The pattern corresponds to the distribution of density in inhabitants and households as shown above.

4.2.7 Gross Floor Area per Inhabitant

Uncertainties in the obtainment of GFA were explained in section 4.2.6. The calculated number is divided by the number of inhabitants to receive a picture on how much built-up space there is for every single person. Figure 45 shows a very clear tendency: GFA per inhabitant is lowest in the north of Altona and in some parts of the city centre. It is highest in the southern and western parts of the borough. Some smaller Statistical Areas show values very different from their surrounding areas. Because of the small sizes, uncertainties could possibly have led to higher inaccuracies.

Figure 45: Illustration of GFA per Inhabitant in the Statistical Areas of Altona (Author, 2018)



4.2.8 Living Area per Inhabitant

Living area should not be confused with GFA, which was presented before. GFA is based on approximate calculations and includes all area of residential buildings. Living area contrarily does not include ancillary areas such as stairs and storage rooms outside the apartment (§2 WoFlV) and is consequently smaller than GFA.

Unfortunately, living area is only recorded at the level of districts. It was provided by HafenCity University (Samoylov & Trede, 2017). The information is therefore much less detailed. Nonetheless, clearly people living in the areas located in the southern parts of Altona are provided with the largest living areas (cf. Figure 46).

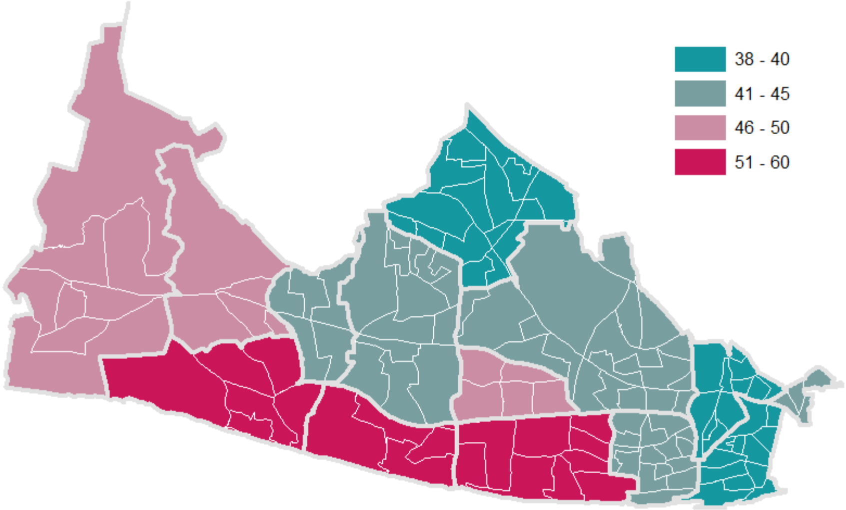


Figure 46: Illustration of Living Area per Inhabitant in m² in the Districts of Altona (Author, 2018)

Regarding GFA per inhabitant as calculated in section 4.2.7, the factor to convert GFA to living area per person is approximately 0.8. District-specific factors were determined in Appendix G. With these factors, GFA is converted to living area at the level of Statistical Areas. The results can be seen in Figure 47. They can be used as approximation to have estimates at the level of Statistical Areas, but do not represent living areas accurately. Also, the distribution is very similar to GFA per inhabitant as shown in section 4.2.7. It is therefore not used in the statistical analysis in chapter 5, but relevant for a comparison with energy targets later on.

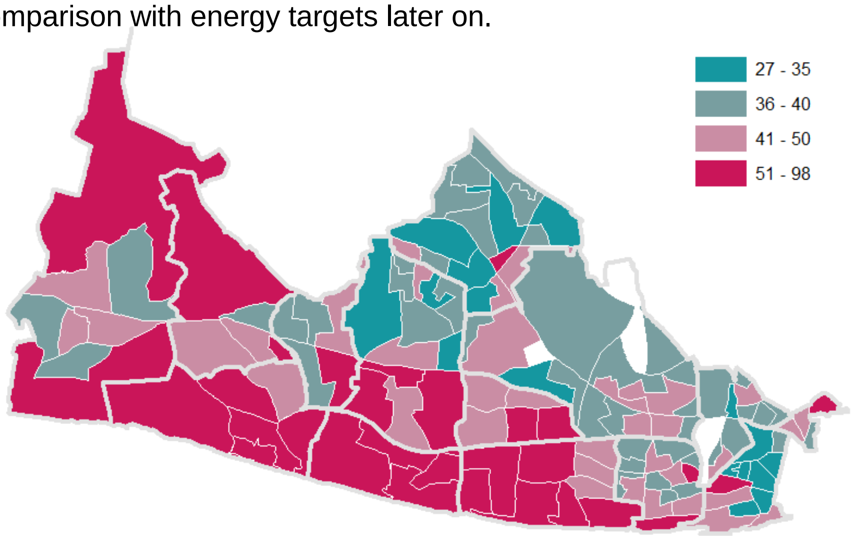


Figure 47: Illustration of Living Area per Inhabitant in m² in the Statistical Areas of Altona (Author, 2018)

4.3 Residents

After density indicators were shown in the previous chapter, this chapter will now present socio-demographic factors of the residents. They refer mainly to the area per inhabitant, age, employment and income.

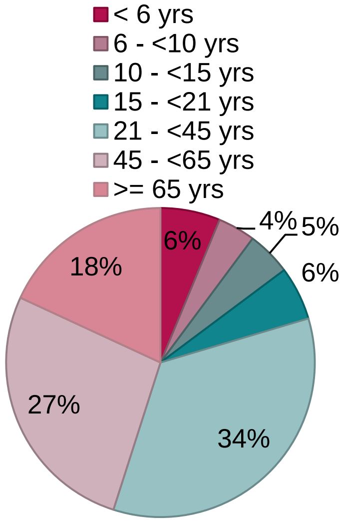


Figure 49: Age of Residents in Altona (adapted from Rogge, 2016)

4.3.1 Age of Inhabitants

The age of Altona's inhabitants is registered in the social indicator table according to seven different age groups. On average, people younger than 21 years represent not even a quarter of all inhabitants (cf. Figure 49). More than half of Altona's residents are between 21 and 65 years old.

To receive a picture of the spatial distribution, the share of households with children in every Statistical Area is considered. The term "children" refers to all inhabitants younger than 18 years. Overall, the pattern is very mixed. However, the share of households with children in the city centre is rather small (cf. Figure 48).

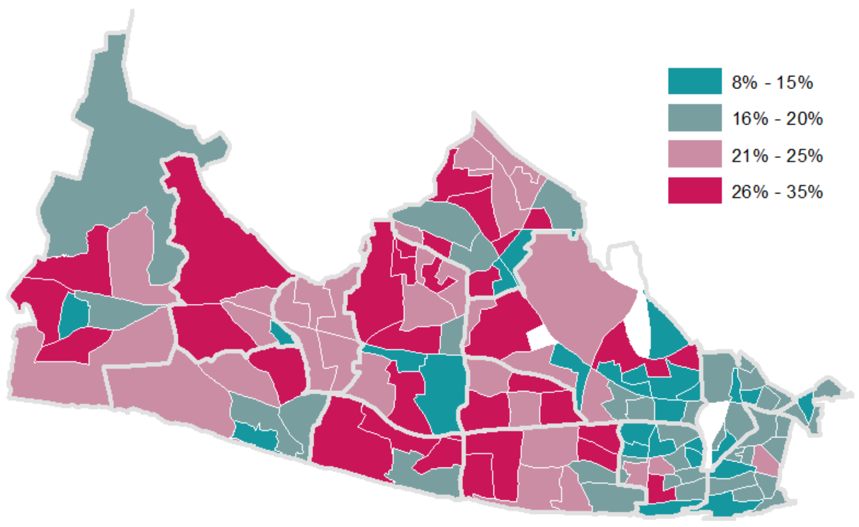


Figure 48: Illustration of the Share of Households with Children in the Statistical Areas of Altona (Author, 2018)

When looking at the share of households with people of at least 65 years the distribution is not as variable. Elderly people are more likely to live in the south-west of Altona (cf. Figure 50). Just like the share of children and teenagers, the share of elderly people is rather small in urban areas.

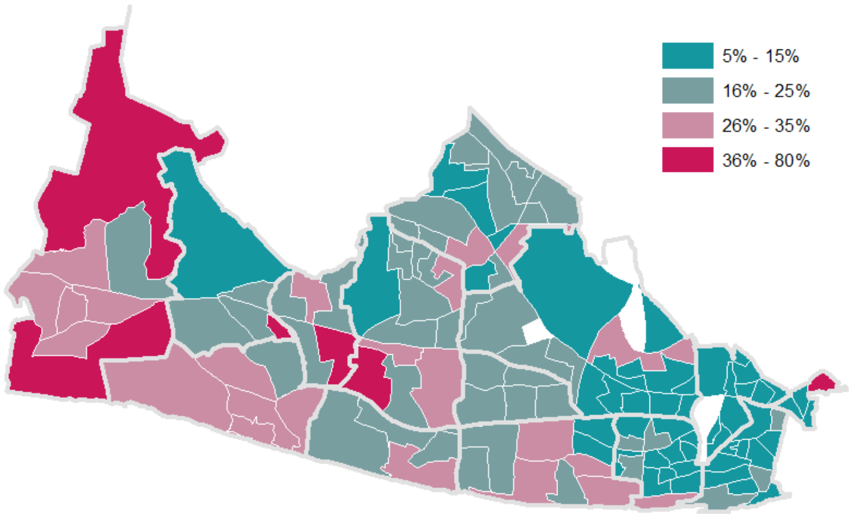


Figure 50: Illustration of the Share of Households with People of at least 65Years in the Statistical Areas of Altona (Author, 2018)

4.3.2 Employment / Unemployment

According to the social indicator tables, the employment rate is given by the number of people with insurable employment divided by all people from age 15 to 64 (cf. Appendix E). The employment rate is comparably high in north and east Altona and low in the west and south (cf. Figure 51).

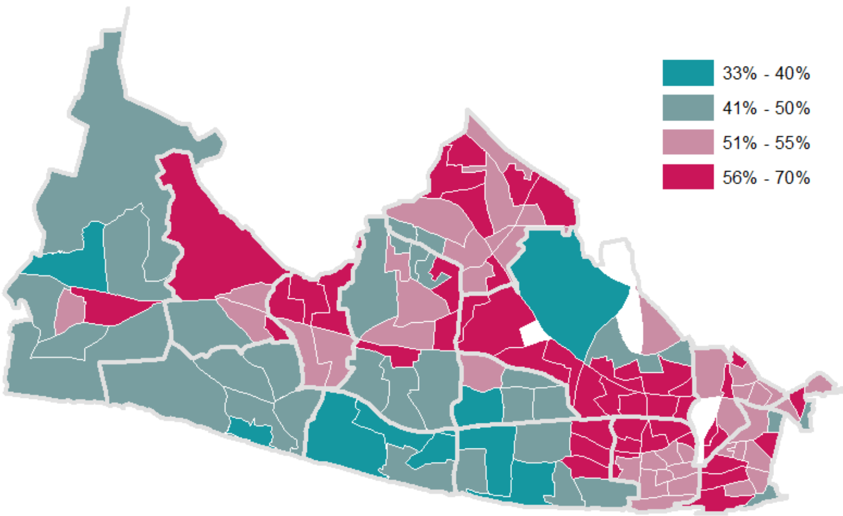
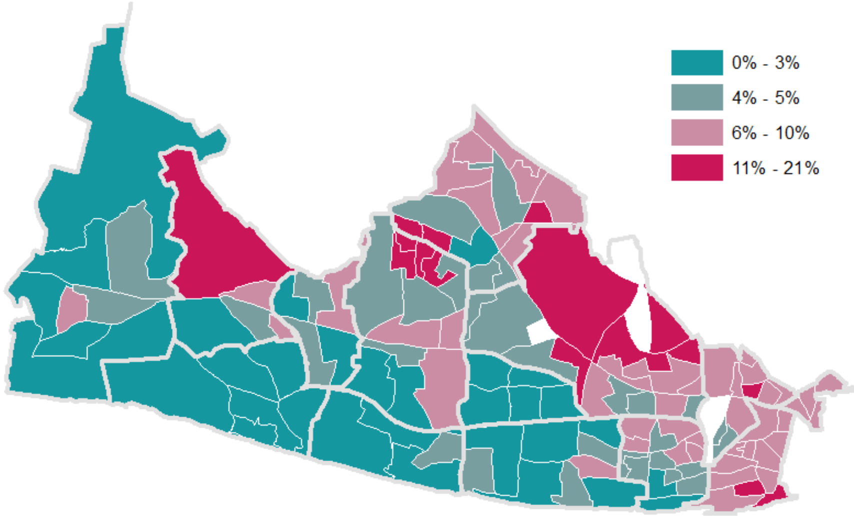


Figure 51: Illustration of the Employment Rate in the Statistical Areas of Altona (Author, 2018)

The unemployment rate is calculated similarly by taking the number of people who receive unemployment benefits (in German: Arbeitslosengeld I and II) and dividing it by all inhabitants aged from 15 to 64. Unexpectedly, the distribution of unemployment is very similar to the distribution of employment. The unemployment rate shows an even more precise spatial pattern. It is high in the north, in particular around Osdorfer Born and northern Bahrenfeld, but also in the south of Altona-Altstadt. The unemployment rate is particularly low in the south-west of Altona (cf. Figure 52).

Figure 52: Illustration of the Unemployment Rate in the Statistical Areas of Altona (Author, 2018)

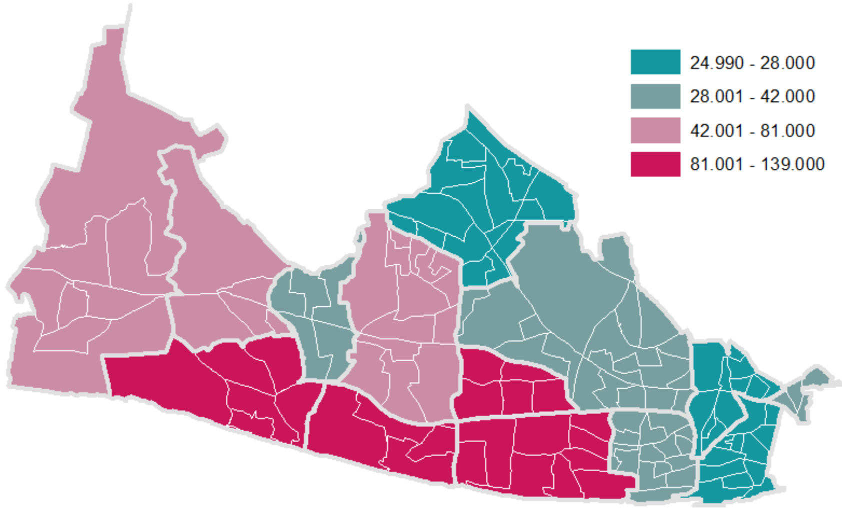


Surprisingly, the distribution of employment and unemployment is not complementary but resembling. The fact that in the south-west both rates are low means that in these areas a third group of people must be residing. This third group consists of people between 15 and 65 years, who are neither registered as employed nor as unemployed. They must have other occupations, which could imply self-employment or education, for example.

4.3.3 Income

More specific information on the financial situation of Altona's inhabitants is given by the annual income per taxable person. All revenues are included. Just like it was the case with living area, data on annual income is only available on the level of districts (cf. Samoylov & Trede, 2017). Despite the fact that this impedes a more detailed picture, the data gives a very good overview on the financial background of Altona's inhabitants. Annual income is lowest close in the east and north and highest in the south, close to the river Elbe (cf. Figure 53). Income is opposed to employment and unemployment

Figure 53: Illustration of Annual Income in the Districts of Altona (Author, 2018)



rate. In areas with low rates of employment and unemployment, annual income is highest.

4.4 Residential Buildings

As the third and last category, this chapter gives an insight on the structure of residential buildings themselves. The main characteristics are social housing, building shape, size, age and type.

4.4.1 Social Housing

The bank IFB Hamburg (Hamburgische Investitions- und Förderbank) supports the construction of apartments for low-income earners. The rent is limited for 15, 20 or 30 years to 6.40 Euro per m² for low incomes (IFB, 2016a, p. 17) and to 8.50 Euro per m² for medium incomes (IFB, 2016b, p. 14). Apartments part of the social housing program need to fulfil the legal energy standard and are funded more if they reach higher standards (IFB, 2016a, p. 27; IFB, 2016b, p. 24). Living area per person in social housing is limited (BSU, 2012, p. 16).

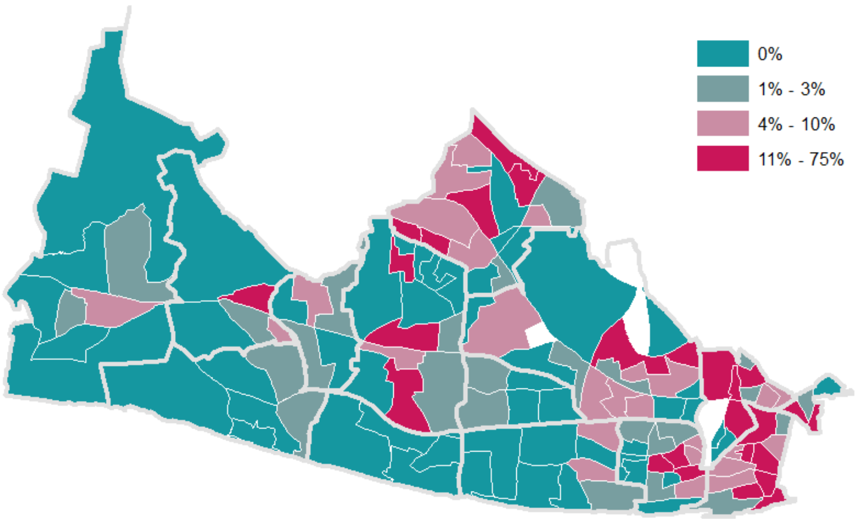


Figure 54: Illustration of the Share of Social Housing in the Statistical Areas of Altona (Author, 2018)

In Altona the largest share of social housing is located in the north-east. Naturally, income was rather low in these areas (cf. Figure 53). The share of social housing in the south-west is extremely low (cf. Figure 54).

4.4.2 Number of Storeys

In data retrieved from ALKIS all residential buildings have an assigned number of full storeys. It does not include storeys with a clearance below 2.30 m and storeys underground (cf. § 2 (6) HBauO). Uncertainties appear through those storeys which do not count as “full storeys“ as well as through the designation of residential buildings, which sometimes are also partly used for other purposes. The numbers can therefore be seen as an approximation to the actual gross floor area for storeys above ground level.

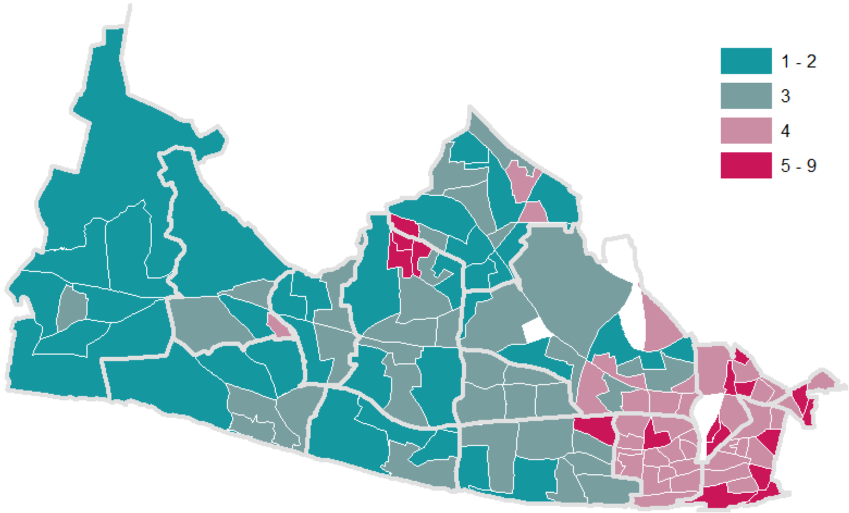


Figure 55: Illustration of the Average Number of Storeys in the Statistical Areas of Altona (Author, 2018)

As shown in Figure 55, buildings located closer to the city centre tend to have at least four storeys. An exception is the area called “Osdorfer Born”, which is located in the district Osdorf/Lurup and consists of high-rise buildings. The spatial distribution of buildings with several storeys explains why density of inhabitants and apartments per hectare was high in these areas (cf. sections 4.2.2 and 4.2.5).

4.4.3 Average A/V Ratio

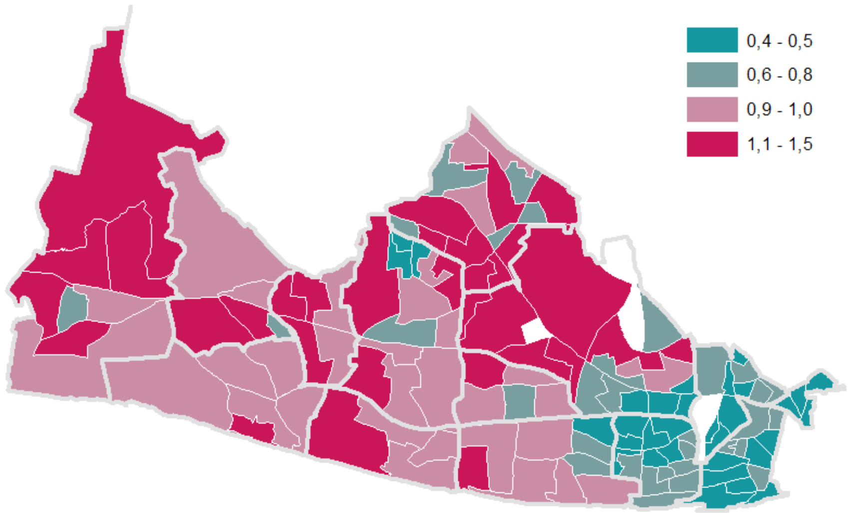


Figure 56: Illustration of the Average A/V Ratio in the Statistical Areas of Altona (Author, 2018)

As shown in section 3.3.6, the building shape and size influences heat losses and therefore energy use. The compactness of a building can be described with the ratio of its surface (A) to its volume (V). This parameter is therefore called A/V ratio (in German: A/V-Verhältnis). A small number indicates less surface area per volume unit, which decreases heat losses through transmission.

For the calculation of A/V ratios of all residential buildings in Altona, an average storey height of 3.50 m is assumed. It is multiplied by the number of full storeys as presented in ALKIS to receive the approximate height of the building (cf. section 4.4.2). Together with the circumference and the base area of a building, the surface area and the volume can be calculated. Pitched roofs and overhangs such as dormers cannot be considered. The received indicator can therefore only be seen as a very approximate approach to the actual A/V ratio including several uncertainties.

On a national level, the average A/V ratio for single family homes is 0.68, for multi-family homes 0.52 and for large apartment buildings 0.38 (Bürger et al., 2016, p. 121). The fact that the calculated values for Altona as shown in Figure 56 are much higher than these averages demonstrates that the uncertainties involved are very high. The results are however still useful, since the relation to one another should still be true.

The lowest average A/V ratios are reached in the more dense areas close to the city centre. Also, the high rise building district Osdorfer Born shows very low values. Higher A/V ratios are reached in the areas located further towards the outskirts (cf. Figure 56). Naturally, the pattern of distribution is opposite to the number of storeys.

4.4.4 Building Age Group

The building age is of importance to understand patterns and correlations between building age and energy use. On a national average, buildings erected between 1949 and 1978 have the highest final energy consumption per square metre, but at the same time show the highest potential of energy savings (BMWi, 2014a, pp. 7, 12).

The Institute for Housing and Environment (German: Institut Wohnen und Umwelt, abbreviated IWU) has created a typology for residential buildings in Germany (Loga et al., 2012), which categorises buildings according to their building age group. These groups are characterised by the epoch in which they were built and the energy regulations that were in force at the time.

Ecofys accumulated some of the groups for their analysis (cf. Hermelink et al., 2013), resulting in a total number of eight building age groups (cf. Table 3). These groups are used in this paper.

Since the average year of construction within an area is only partially meaningful, the indicator used to express building periods in Altona is the share of GFA of each building age group in every statistical area.

Building Age Groups used by Ecofys (Hermelink et al., 2013, p. 5)	Building Age Groups defined by IWU (Loga et al., 2012)			Regulation (Loga et al., 2012, p. 11)
1	...	-	1859	
	1860	-	1918	
2	1919	-	1948	
3	1949	-	1957	
4	1958	-	1968	Requirements on thermal insulation (DIN 4108)
5	1969	-	1978	
6	1979	-	1983	1st thermal protection ordinance
7	1984	-	1994	2nd thermal protection ordinance
8	1995	-	2001	3rd thermal protection ordinance
	2002	-	2009	Energy saving ordinance (EnEV 2002)
	2010	-	2015	Energy saving ordinance (EnEV 2009)

Table 3: Building Age Groups defined by IWU and used by Ecofys

In their analysis, Ecofys did not identify the building age of all buildings in the borough Altona. On average, nearly 80 % of all GFA was identified with a building age. Some Statistical Areas are covered by 100 %, while others are represented far less, with the Statistical Area 34001 in Rissen being the least represented area. The amounts of coverage of every Statistical Area are shown in Appendix F. The use of data in less represented areas leads to uncertainties in the analysis. Nevertheless, there is currently no better data on the epoch buildings were erected in.

Areas close to the city centre tend to have a higher share of old buildings, while recent building activity has mostly taken place in areas further in the outskirts. However, there are some irregularities. The distribution of building ages represented in every Statistical Area is shown in Figure 57 to Figure 63.

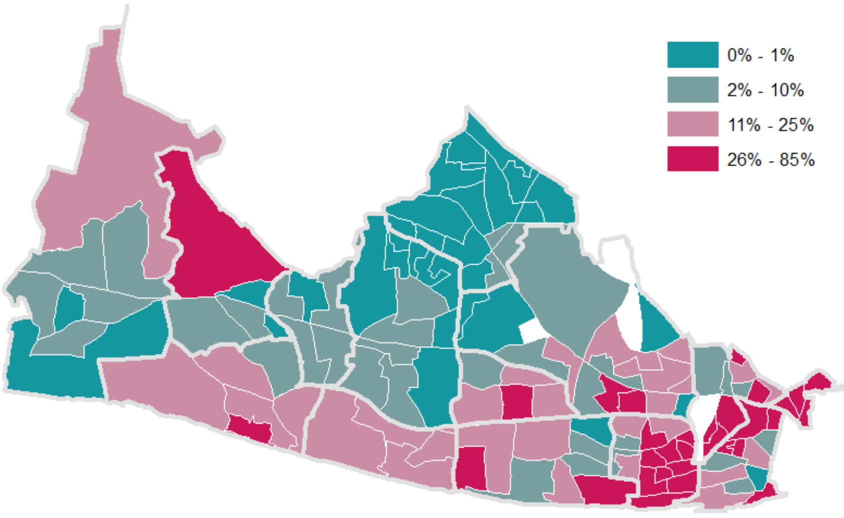


Figure 57: Illustration of the Share of Building Age Group 1 (before 1918) in the Statistical Areas of Altona (Author, 2018)

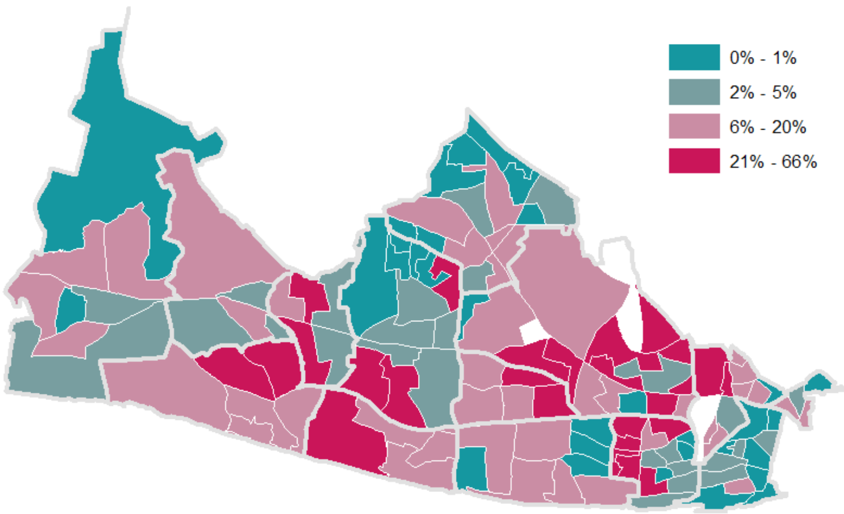


Figure 59: Illustration of the Share of Building Age Group 2 (1919-1948) in the Statistical Areas of Altona (Author, 2018)

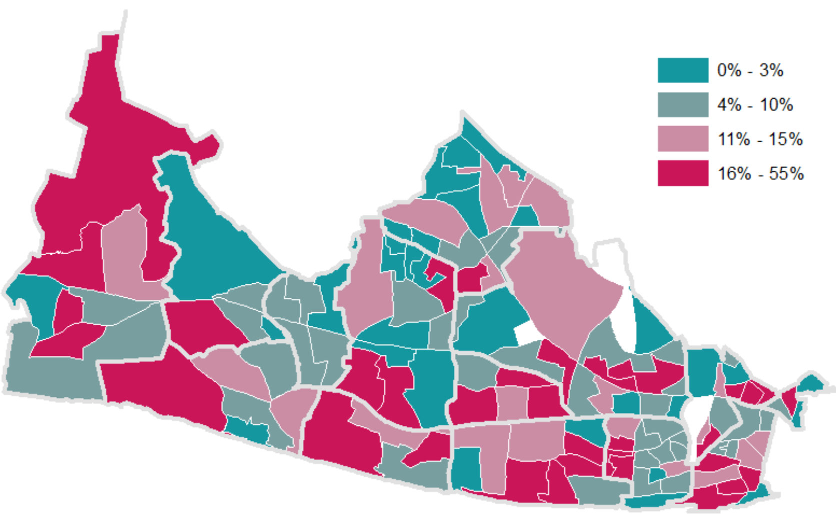


Figure 58: Illustration of the Share of Building Age Group 3 (1949-1957) in the Statistical Areas of Altona (Author, 2018)

Figure 62: Illustration of the Share of Building Age Group 4 (1958-1968) in the Statistical Areas of Altona (Author, 2018)

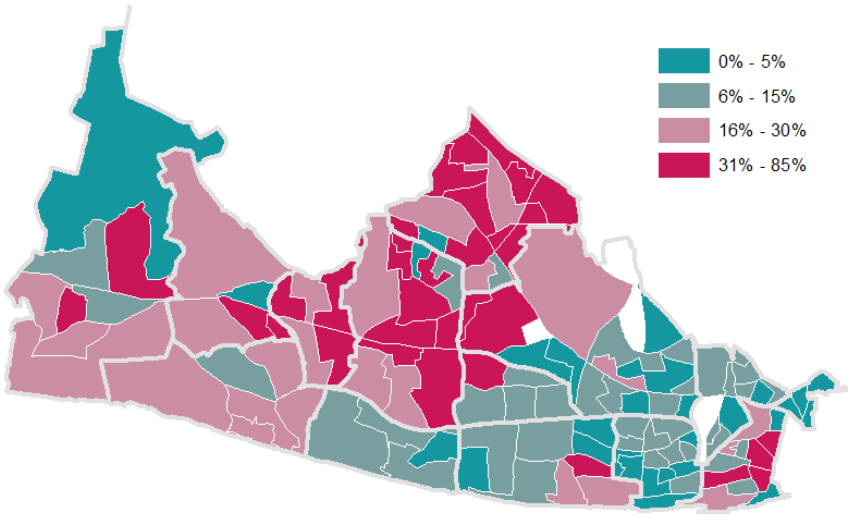


Figure 61: Illustration of the Share of Building Age Group 5 (1969-1978) in the Statistical Areas of Altona (Author, 2018)

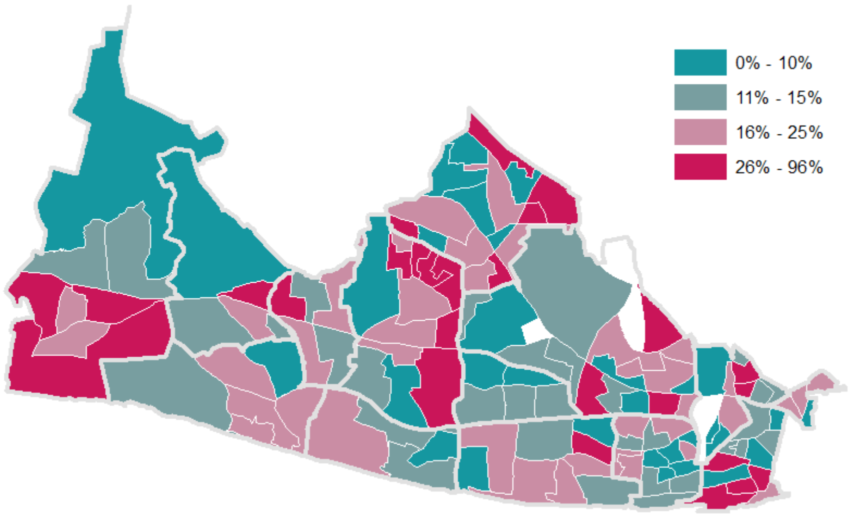
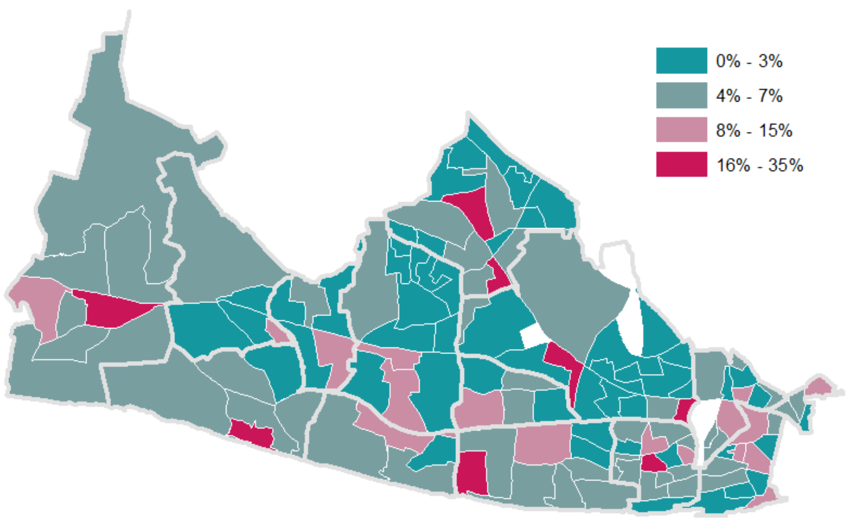


Figure 60: Illustration of the Share of Building Age Group 6 (1979-1983) in the Statistical Areas of Altona (Author, 2018)



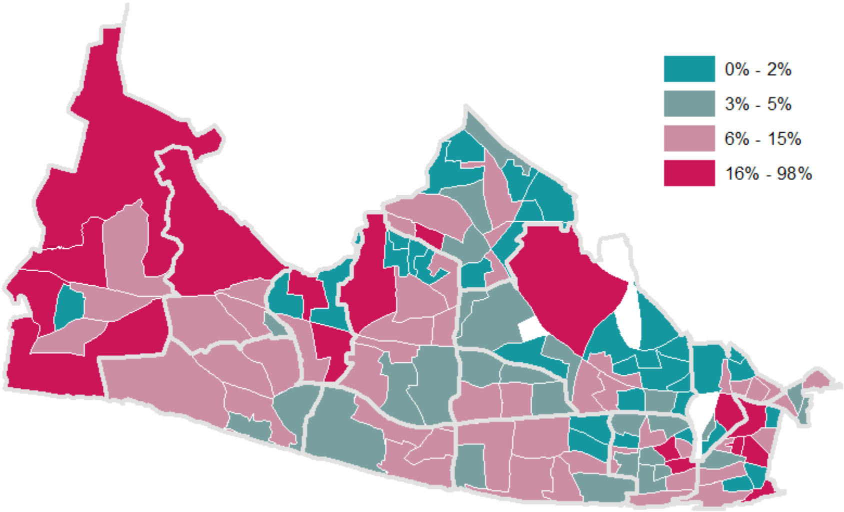


Figure 64: Illustration of the Share of Building Age Group 7 (1984-1994) in the Statistical Areas of Altona (Author, 2018)

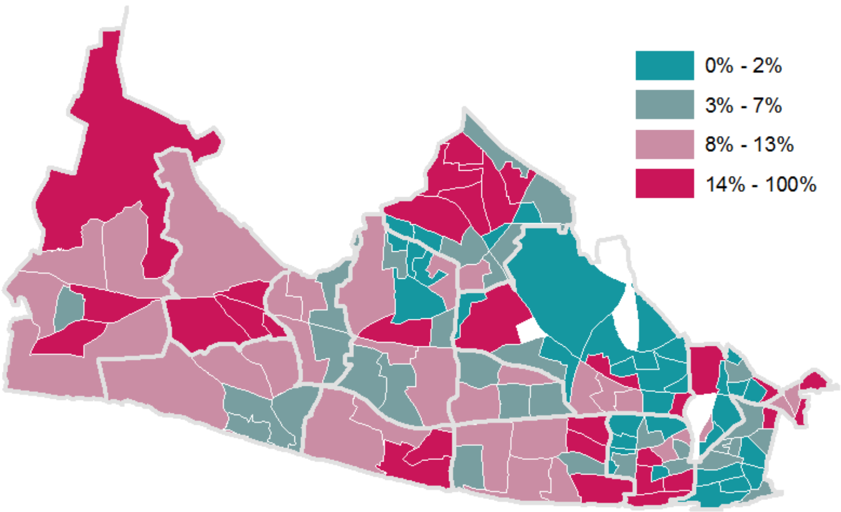


Figure 63: Illustration of the Share of Building Age Group 8 (after 1995) in the Statistical Areas of Altona (Author, 2018)

4.4.5 Building Type

In addition to building periods, the IWU also came up with a classification of building types for residential buildings (cf. Loga et al., 2012, p. 14). Ecofys used a similar classification as shown in Table 4, which will also be used in this paper.

Building type used by Ecofys (Hermelink et al., 2013, p. 5)	English meaning
freist. EFH / DHH	Single family / semi-detached houses
Reihenhaus	Terraced houses
MFH-Einzelhaus	Apartment building (detached)
MFH-Gruppenhaus	Apartment building (group house)
MFH-Wohnblock	Apartment building (block)
MFH-Hochhaus	Apartment building (high-rise)

Table 4: Building Types defined by IWU and used by Ecofys

Again, the indicator expresses the share of GFA of every building type. The average coverage of GFA identified with a typology is 80 %, ranging from 14 % in the Statistical Area 28011 in Lurup to 100 % several other Statistical Areas. The amounts of all Statistical Areas are shown in Appendix F. It is essential for the further analysis to be aware of these uncertainties.

In Altona, most single-family houses can be found in the western parts, but also in other districts such as Lurup and Othmarschen. Areas close to the city centre however show a very clear picture. Here, single and two-family-houses have a share below 15% (cf. Figure 65 to Figure 70.

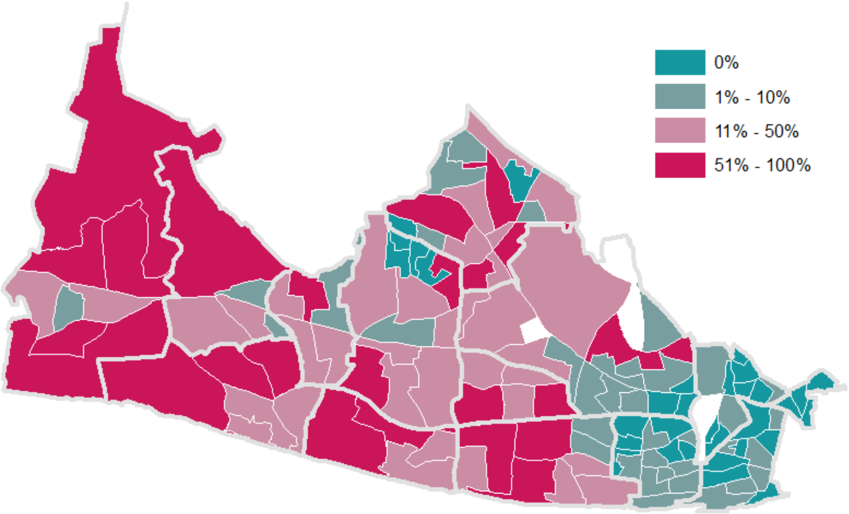


Figure 65: Illustration of the Share of Building Type 1 (Single Family Houses) in the Statistical Areas of Altona (Author, 2018)

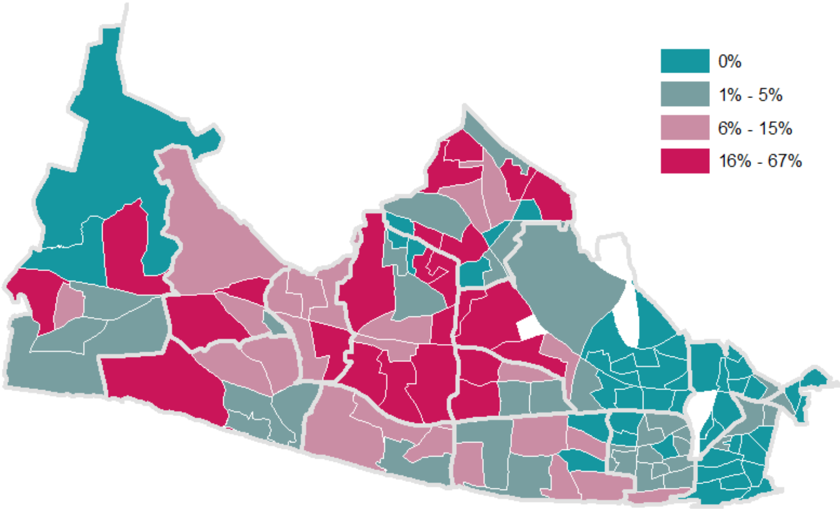


Figure 66: Illustration of the Share of Building Type 2 (Terraced Houses) in the Statistical Areas of Altona (Author, 2018)

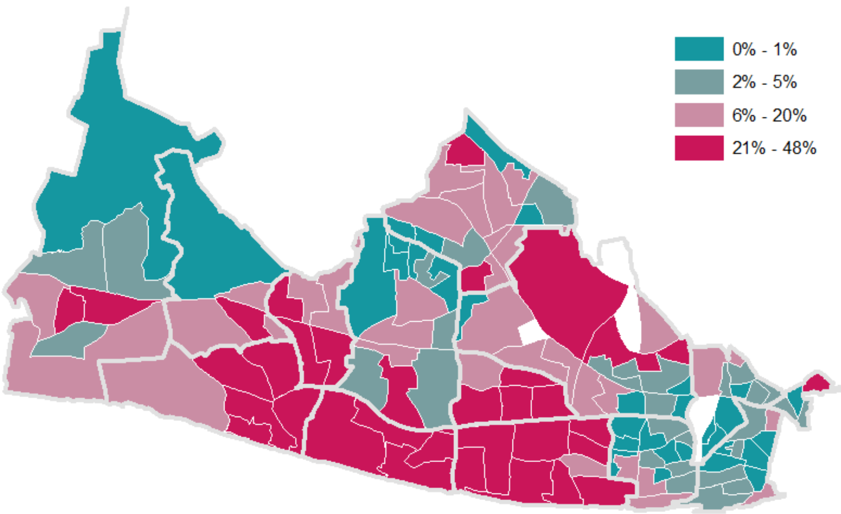


Figure 67: Illustration of the Share of Building Type 3 (Detached Apartment Building) in the Statistical Areas of Altona (Author, 2018)

Figure 68: Illustration of the Share of Building Type 4 (Apartment Building, Group House) in the Statistical Areas of Altona (Author, 2018)

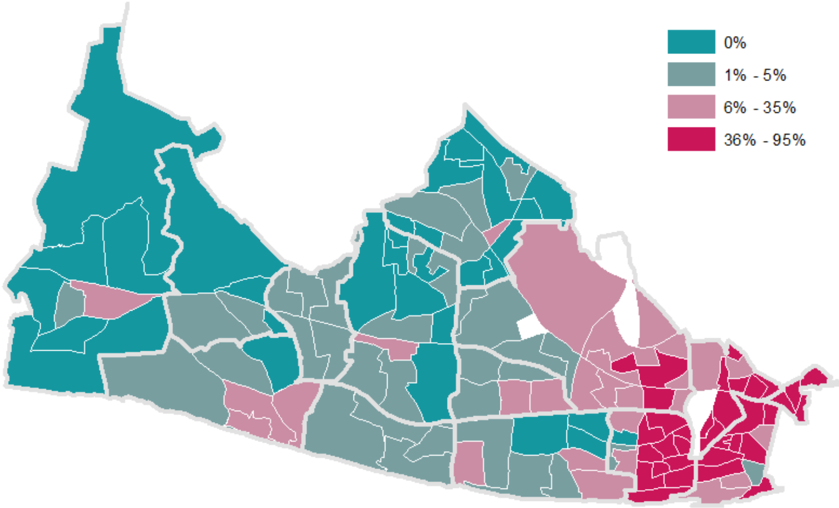


Figure 69: Illustration of the Share of Building Type 5 (Apartment Building, Block) in the Statistical Areas of Altona (Author, 2018)

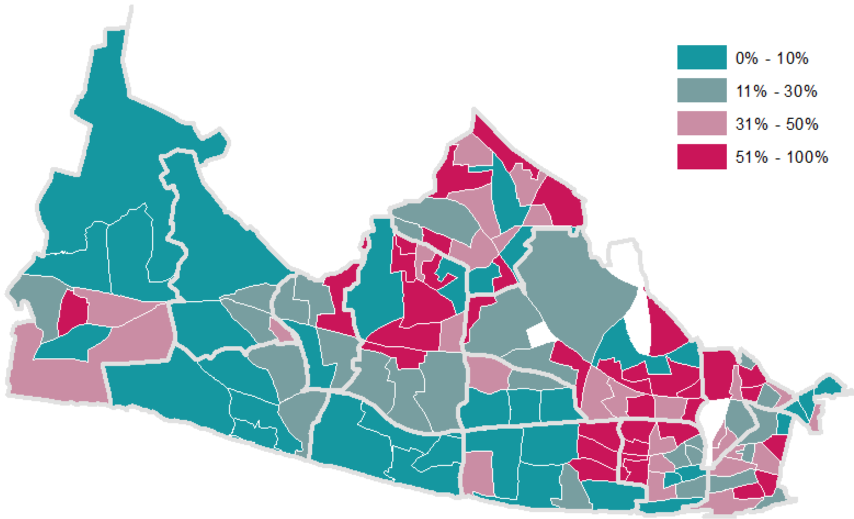
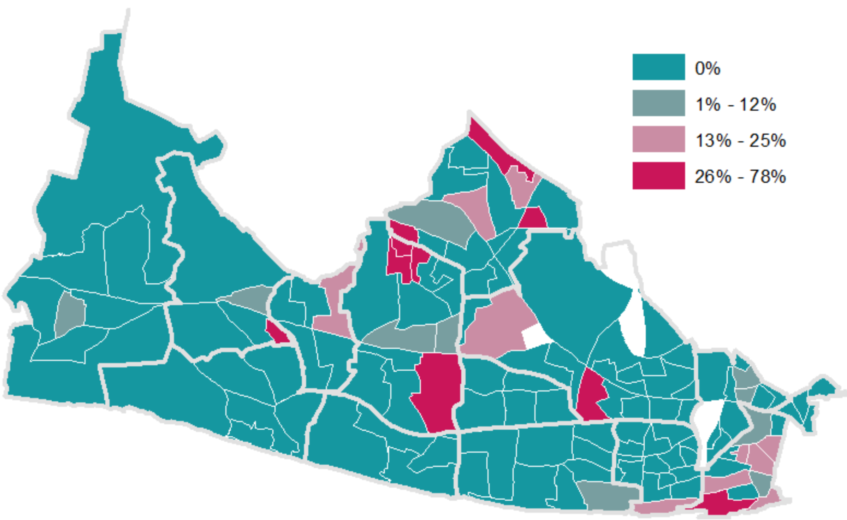


Figure 70: Illustration of the Share of Building Type 6 (Apartment Building, High-rise) in the Statistical Areas of Altona (Author, 2018)



4.5 Energy Use for Electricity in Residential Buildings

Data on electricity consumption in Altona was provided by Stromnetz Hamburg GmbH. A detailed description of the data and its modification can be found in Appendix H. This section first explains the uncertainties involved in the data in further detail, then moves on to total electricity consumption and per inhabitant, and ends with emissions resulting from electricity use.

4.5.1 Uncertainties

Since the provided data is based on readings of meters installed in the electricity grid, only electricity uses of the grid are included. When electricity is generated on site through for example photovoltaic and does not run through the electricity grid, it is not included in the data. The data consequently lacks some minor amounts of electricity use.

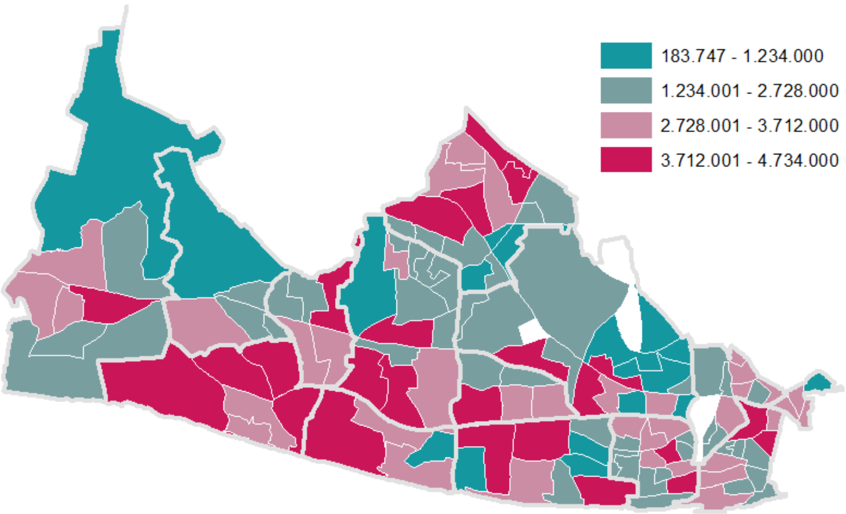
As shown in section 3.3.5, on a national average in 2015 electricity in private households was mainly used for lighting (8 %), mechanical energy (cooling and freezing, devices for communication and entertainment) (44 %) and other process heat (cooking, hot water for dishwasher and laundry machine) (29 %). However, some households also use electricity for hot water (12 %) and heating (7 %). Statistically, it is difficult to separate electricity consumption by its designated use. As explained by a staff member of Stromnetz Hamburg GmbH, heat pumps and night storage heaters have their own meters. Unfortunately, the evaluation of these meters is not separated by private and commercial use, which is why the data cannot be used for the analysis of this paper. Flow heaters and electric heating on the other hand are included in the general meter (Schlicht, 2018; cf. Appendix H). This means, that the data on electricity consumption as used in this paper completely includes lighting, mechanical energy and other process heat, but only partly includes electricity used for hot water and heat energy.

Additionally, the data given by Stromnetz Hamburg GmbH was evaluated on a street level. The data had to be converted from the level of streets to the level of Statistical Areas. The explanation of this procedure can be found in Appendix H. While it is as accurate as possible, it leads to further uncertainties and possible inaccuracies.

4.5.2 Electricity Consumption

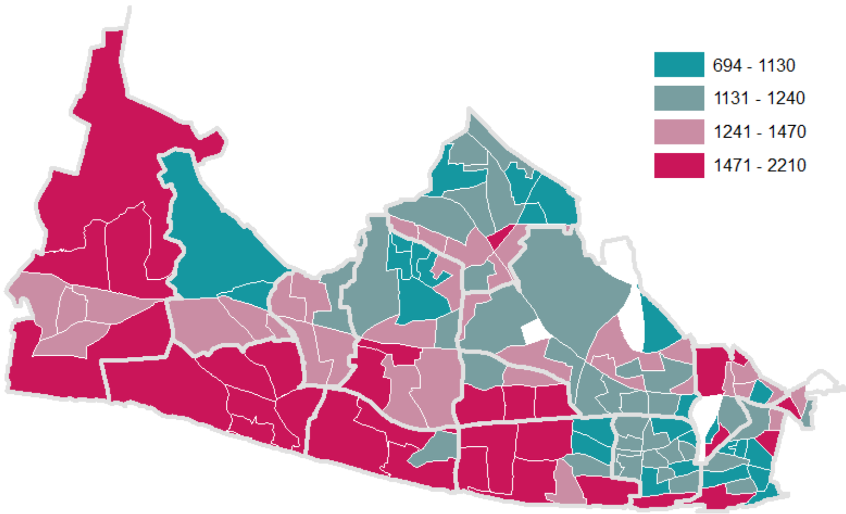
The spatial distribution of total electricity use shows a very mixed picture. There is no real pattern standing out. Generally speaking, the southern districts Blankenese and Nienstedten as well as the northern part of Lurup show higher amounts of energy use. Total amounts without relation to the size or the number of inhabitants of a Statistical Area is only very little meaningful.

Figure 71: Illustration of total Electricity Consumption (kWh) in the Statistical Areas of Altona (Author, 2018)



Total electricity consumption is hence converted to electricity use per person. The results as shown in Figure 72 are much clearer in their distribution. Residents in the west and south of Altona used much more electricity than residents in districts located in the north and in the city centre. Annual electricity consumption varies from 700 kWh to 2200 kWh per person.[I] These values are in line with variances given

Figure 72: Illustration of Electricity Consumption per Inhabitant (kWh/capita) in the Statistical Areas of Altona (Author, 2018)



[I] The Statistical Area 22004 in the very north-east part of Altona had to be excluded. According to the data, only a small number of people (246) lived here in 2015. When calculating electricity use per inhabitant, an abnormally and unrealistically high value is reached (3,555 kWh/capita). The reason for this discrepancy in electricity use and number of residents remains unexplained.

by the Stromspiegel (cf. Appendix J).

The frequency of electricity use per inhabitant for every Statistical Area is shown in the following histogram. The data is not normally distributed, since the histogram is not symmetrical. In most Statistical Areas, people have used between 1000 kWh and 1800 kWh of electricity in 2015.

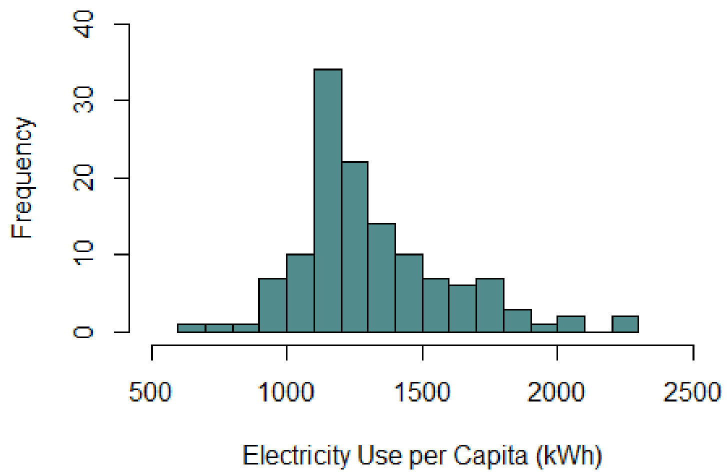


Figure 73: Histogram of Frequencies in Electricity Consumption per Inhabitant in the Statistical Areas of Altona (Author, 2018)

A more detailed picture on the distribution of electricity consumption per inhabitant is given by the scatterplot as shown in Figure 74. Some districts such show general tendencies, while most others have a wide spread or single outliers. The great diversity within districts emphasizes the importance to move at the lower level of Statistical Areas.

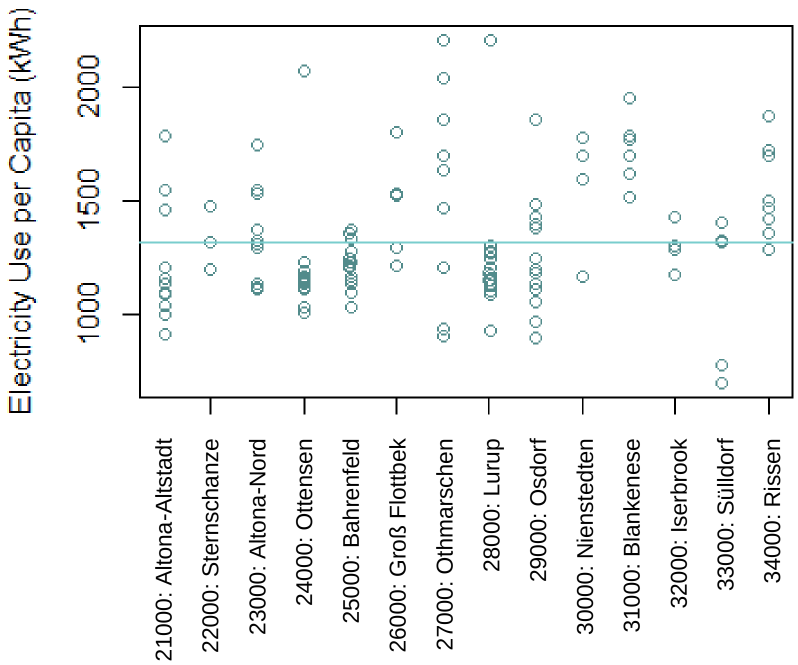


Figure 74: Scatterplot of Electricity Consumption per Inhabitant in the Statistical Areas of Altona (Author, 2018)

4.5.3 Generation of Electricity

Generally, electricity is not generated at its place of use. Power plants are located in several places inside but also outside the city. Electricity is then transported to its place of use. Since there is only one grid for electricity, generated electricity from all types of energy sources runs through it. The national electricity mix was shown in section 3.3.4. Its main source was hard coal and lignite (42 %) and renewable energy sources (28 %).

The end user can influence the electricity grid by entering into contract with a certain electricity supplier. To draw a more differentiated picture on GHG emissions per consumed electricity unit, one could assume that the end user only receives the electricity mix he ordered. Unfortunately, contracts between inhabitants and electricity suppliers are not available. In consequence, there is currently no way to determine the number of people who signed up for electricity generated by renewable energy sources, even though the emission factor for their consumed amount of electricity would have to be lower. Instead, the emission factor calculated for Hamburg is used for all Statistical Areas in Altona (cf. section 3.4.3).

4.5.4 CO_2 Emissions resulting from Electricity Consumption

To calculate the amount of GHG emission resulting from electricity consumption, data of electricity use (cf. section 4.5.2) is multiplied by the emission factor. For an exact calculation, the electricity mix of every Statistical Area would need to be known. It is possible for the operator of the electricity grid to determine the electricity supplier of every extraction point, but that alone does not define the electricity mix, yet. Suppliers offer different products and the choice of product within the chosen supplier is not available to the grid operator

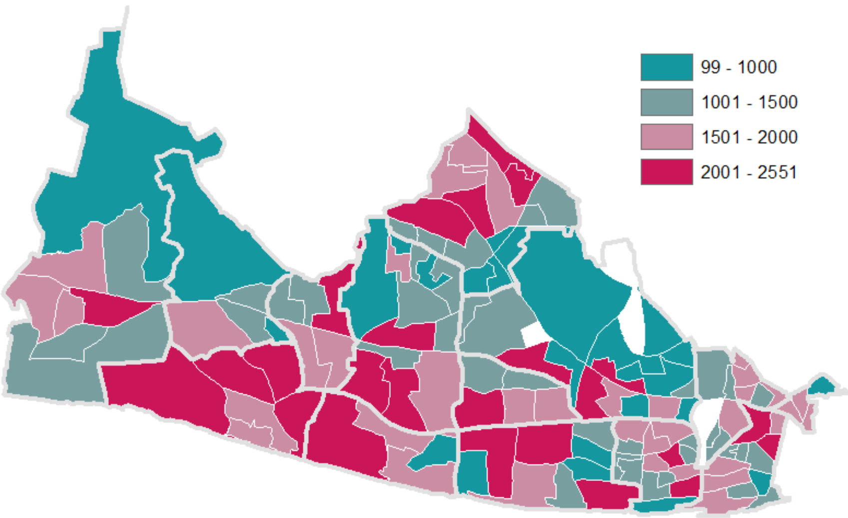


Figure 75: Illustration of total direct CO_2 Emissions deriving from Electricity Use in the Statistical Areas of Altona (Author, 2018)

(Schlicht, 2018). Currently it is impossible to geographically differentiate between shares of energy sources used for the generation of electricity. Thus, a universal emission factor is used for the entire borough. It includes only direct CO_2 emissions, which is the predominant part of emissions in the generation of electricity, and was estimated at 539 g CO_2/kWh (cf. section 3.4.3).

Due to the multiplication by one universal factor, the geographical pattern of total CO_2 emission resulting from electricity use (cf. Figure 75) is consequently the same as the pattern of total electricity consumption (cf. Figure 71). Direct emissions range from 100 t CO_2 to over 2,500 t CO_2 per Statistical Area.

Similarly, the pattern of CO_2 emissions per capita (cf. Figure 76) is the same as that of electricity use per capita (cf. Figure 72). In most Statistical Areas, inhabitants were responsible for between 0.6 t CO_2 to 1.0 t CO_2 because of their electricity consumption.

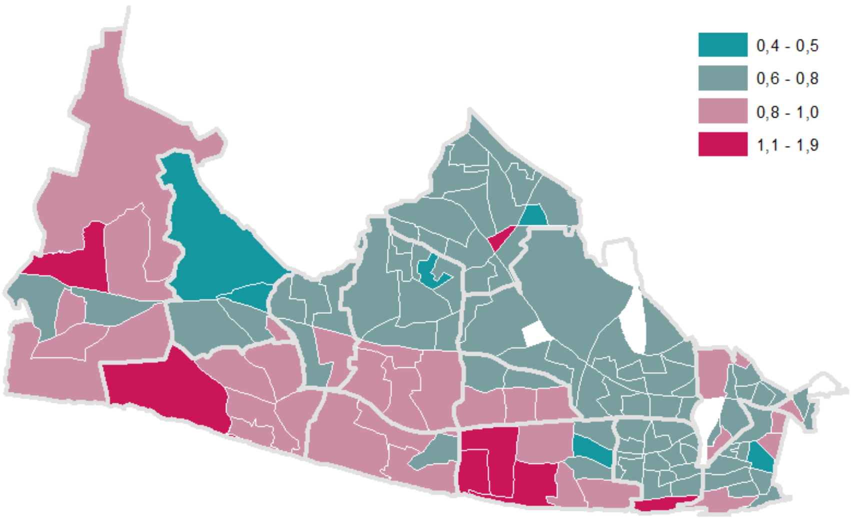


Figure 76: Illustration of total direct CO_2 Emissions per Inhabitant deriving from Electricity Use in the Statistical Areas of Altona (Author, 2018)

4.6 Energy Use for Heating in Residential Buildings

Data on energy use for heating was provided for consumption of gas by Gasnetz Hamburg GmbH and for district heat by Vattenfall Europe Sales GmbH, URBANA Energiedienste GmbH and HanseWerk Natur GmbH. Details about the data compilation for heat energy use are explained in Appendix I with the factor for temperature adjustment determined in Appendix D.

In accordance with previous chapter, uncertainties involved in the analysis are explained, then heat energy use is illustrated and finally emissions are calculated.

4.6.1 Uncertainties

As explained above, data was available for energy generated by gas and district heat. This is due to the fact, that gas and district heat reach the consumer through a grid, which is operated by a company. Bundled data on consumption can therefore be received by these companies. Petroleum and renewable energy sources used on site however do not use such a grid. Consumption values are therefore only tracked by the owner and could only be received if every household was approached individually.

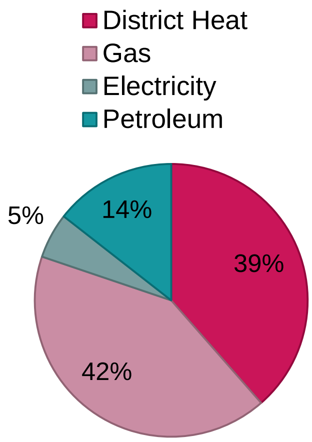


Figure 77: Share of Apartments with different Types of Heat Generation in Hamburg (adapted from Destatis, 2016, pp. 20, 22)

Gas and district heat do not cover all energy uses for heating. The data used in section 3.3.5 shows that on a national level in 2015 only 57 % of hot water and 56 % of heating were generated by gas and district heat. In Hamburg the share seems to be higher. According to the micro census from 2014, 80 % of all apartments receive their heat through district heat or generate it with gas. The remaining 20 % of apartments use electricity or petroleum for heat generation, varying from 18 % for rented flats to 28 % for condominiums (cf. Figure 77; Destatis, 2016, pp. 20, 22). As explained before, these data were not available.

Based on this study, it is assumed that only 80 % of energy used for heating is represented by the given data on gas and district heat. The given amounts are therefore multiplied by a factor of 1.25, so that they approximate the actual amount of energy use. It is essential to note that this vague assumption cannot represent reality, since the share of households heated by other sources most likely varies from one Statistical Area to another.

4.6.2 Heat Energy Use

Total amounts of heat energy use in the Statistical Areas in 2015 vary from 0.6 GWh to 60 GWh. The largest amounts are used in the centre of Altona (cf. Figure 78), but again, these amounts are more representative, when put in relation to the number of inhabitants.

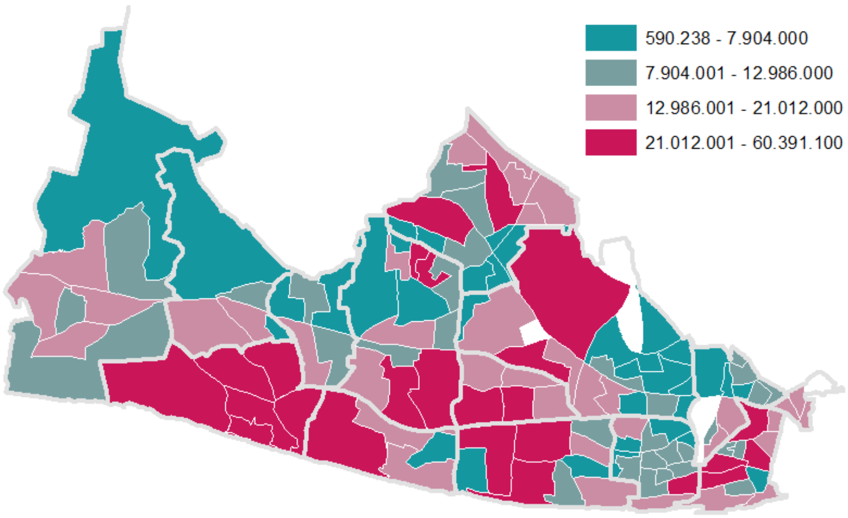


Figure 78: Illustration of total Heat Energy Consumption (kWh) in the Statistical Areas of Altona (Author, 2018)

A number of Statistical Areas had to be excluded from the further analysis and are therefore left blank in the maps. The exclusions are explained in Appendix I. The geographical distribution of heat energy use per capita shows a very clear pattern. In the Statistical Areas located in the north-east of Altona, inhabitants mostly used less than 6500 kWh of heat energy in 2015. Heat energy consumption in other parts of Altona was higher, exceeding 10,000 kWh in the areas located close to the river Elbe.

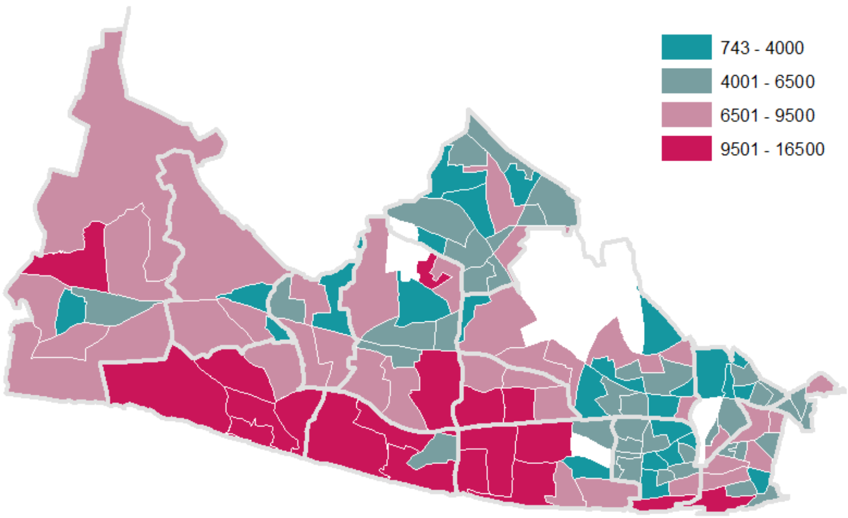


Figure 79: Illustration of Heat Energy Consumption per Inhabitant (kWh/capita) in the Statistical Areas of Altona (Author, 2018)

Frequencies in heat energy use per capita display a broader spread than those of electricity use. In most Statistical Areas, people have consumed between 3,000 kWh and 10,000 kWh of heat energy, but several Statistical Areas are outside this range (cf. Figure 80).

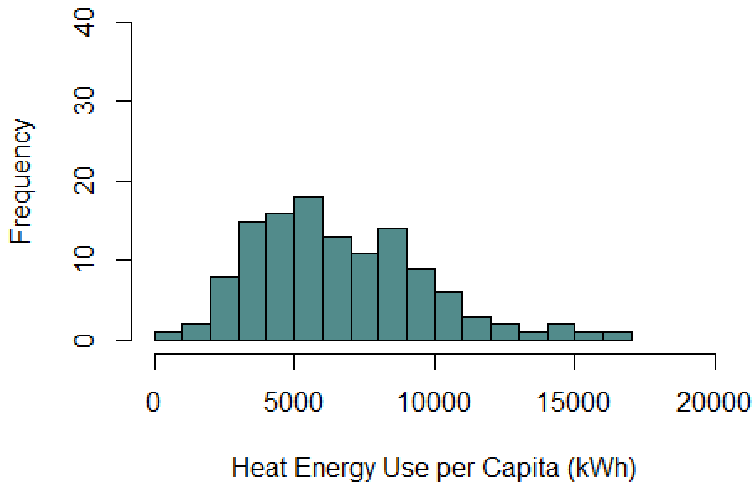


Figure 80: Histogram of Frequencies in Heat Energy Consumption per Inhabitant in the Statistical Areas of Altona (Author, 2018)

The spread of heat energy use per capita for every Statistical Area assembled by district is shown in Figure 81. In some districts such as Groß Flottbek and Blankenese heat energy use per inhabitant is above average. As explained before, only energy sources using grids are included in the analysis. Regarding Statistical Areas with very low consumption values, it can therefore be speculated, if heat energy supply is partly covered by off-grid solutions such as wood pellets. These speculations cannot be proved here and are therefore simply accepted as uncertainty.

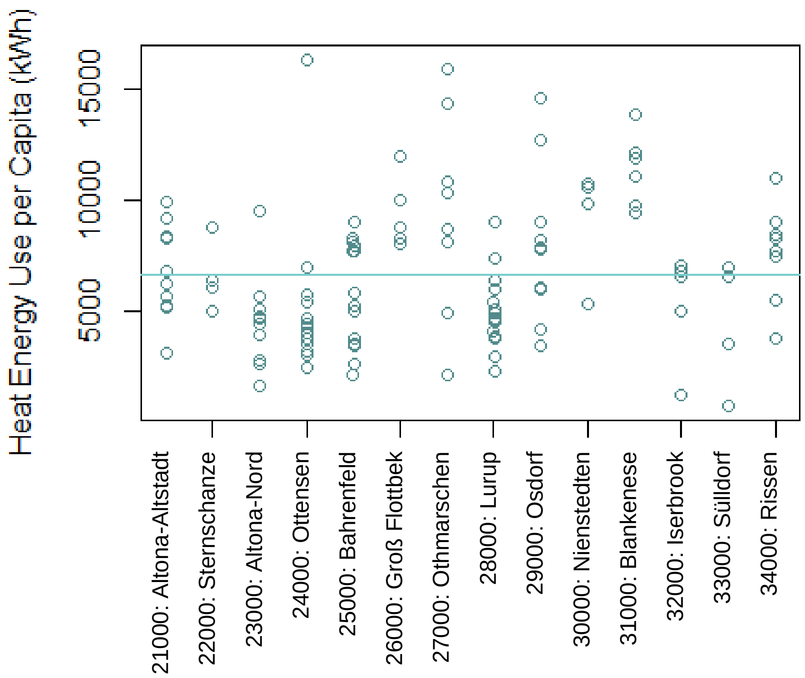


Figure 81: Scatterplot of Heat Energy Consumption per Inhabitant in the Statistical Areas of Altona (Author, 2018)

4.6.3 Generation of Heat Energy

Regarding the size of the heating system, the census in 2011 has shown that in Altona only 10 % of all residential buildings were heated at the level of individual stoves or floors, while 70 % of all buildings were heated on the level of the building. The remaining 20 % are even heated on the level of several blocks (BUE, 2017a). These high levels of operation can help transforming heating systems, since it is not the individual that needs to be addressed.

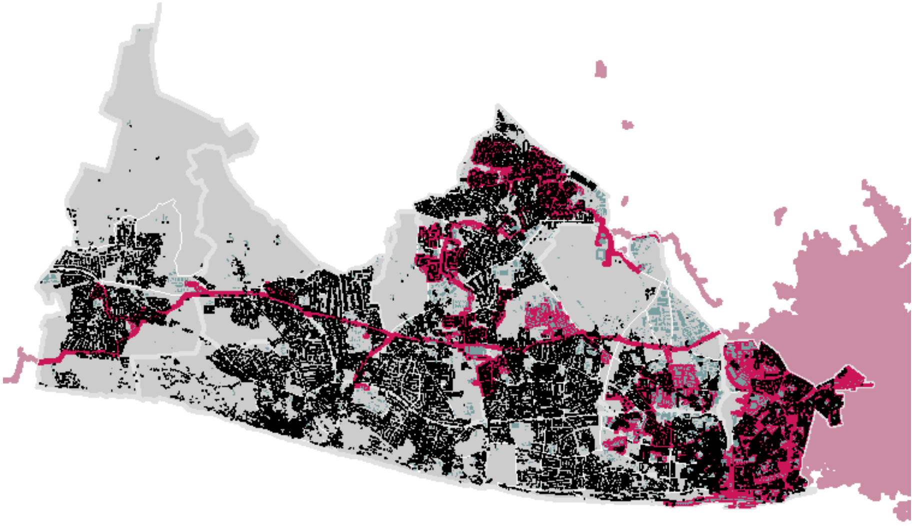


Figure 82: District Heat in Altona (Author, 2018)

The share of apartments supplied with different energy sources for heating were shown in Figure 77. 39 % of apartments in Altona receive heat energy through district heat. The rough location of distrit heating pipelines and areas covered by district heat are highlighted in red in Figure 82. Most of the inner city is supplied with district heat, but also other parts in the north and middle of Altona.

District heat is generated elsewhere and then transmitted through a grid to the customer. What energy source is behind district heat? Information on district heat in Altona can be found at the online platforms MetaVer (short for MetadatenVerbund) or alternatively Geoportal Hamburg. The authorities of the state serve as information provider. The platforms facilitate a visualization of areas supplied by district heat and the associated heat generation and were used as basis for the analysis in this paper.

The largest grid of district heat is operated by the Swedish company Vattenfall GmbH (in the following called Vattenfall). Its energy sources are:

- black coal in the cogeneration plant Wedel (in German: “Heizkraftwerk Wedel”) in the west at the riverbank, just outside of Hamburg (in 1987 change from electricity to heat generation),
- fuel oil in the heat plant EEZ (in German: “Heizwerk EEZ”) at the Elbe-Einkaufszentrum (EEZ) in the middle of the borough Altona (put into operation in 2008)

- gas and fuel oil in the heat plant Haferweg (in German: “Heizwerk Haferweg”) in Altona Nord (put into operation in 2017)

Since the grid of Vattenfall stretches through all Hamburg, the emission factor calculated by the statistical office for Hamburg is used for heat energy consumptions within this grid. The factor was 314 g CO_2/kWh (cf. section 3.4.4).

The second largest provider of district heat in Altona is the local company HanseWerk Natur GmbH (in the following called HanseWerk Natur). It operates several local grids, which all use gas as energy source. The associated emission factors were sent by HanseWerk Natur (Schlaug, 2018). Matthias Sandrock from Hamburg Institut Research gGmbH explains that when suppliers calculate their own emission factors, they often use other calculation methods, which leads to lower values (2014, p. 30). Due to the lack of alternatives, these are still used in further analyses.

- “Verbund West”: Heat is generated in the cogeneration units “BHKW Spreestraße” (in MetaVer named “Heizwerk Kleiberweg”) and “BHKW Schnackenburgallee 153” as well as the heat plant “Schnackenburgallee 100” emission factor: 92 g CO_2/kWh
- “Bahrenfelder Chaussee/Theodorstraße”: Heat is generated in the heat plant “HW Theodorstraße” emission factor: 239 g CO_2/kWh
- “Verbund Lyserstraße”: Heat is generated in the heat plants “HW Lyserstraße” and “HW Baurstraße” emission factor: 88 g CO_2/kWh
- “Verbund Altona”: Heat is generated in the heat plant “HW Paul-Ehrlich-Straße” (in MetaVer named “AK Altona”) emission factor: 308 g CO_2/kWh
- “Behringstraße”: Heat is generated in the cogeneration unit “BHKW Behringstraße” (not shown on MetaVer) emission factor: 177 g CO_2/kWh

The third operator of district heat grids in Altona is URBANA Energiedienste GmbH (in the following called Urbana). It uses gas as energy source as well and operates the following grids:

- “Osdorf”: by gas in a cogeneration unit
- “Luruper Chaussee”: by gas in a cogeneration unit
- “Friedrich-Ebert-Hof”: by gas in a cogeneration unit
- “Othmarschen”: by gas in a cogeneration unit

For these grids, no emission factor was available. Since the energy source is gas and the power plants are cogeneration units, the emission factor should be rather low. It is assumed at 100 g CO_2/kWh.

As shown, the large grid run by Vattenfall still uses coal as energy source. Its district heat therefore has the highest emission factor. Renewable energy sources do not seem to play a large role in the generation of district heat.

4.6.4 CO_2 Emissions resulting from Heat Energy Consumption

To receive emissions, heat energy consumption is multiplied by the associated emission factors. All factors only include direct CO_2 emissions. The emission factor for gas is approximately 230 g CO_2/kWh (cf. section 3.4.4)[I]. Most local heat grids have emission factors below that of gas, but some grids run by HanseWerk Natur and the main grid of Hamburg run by Vattenfall have higher emission factors (cf. section 4.6.3). They are less environmentally friendly than gas as heat energy source.

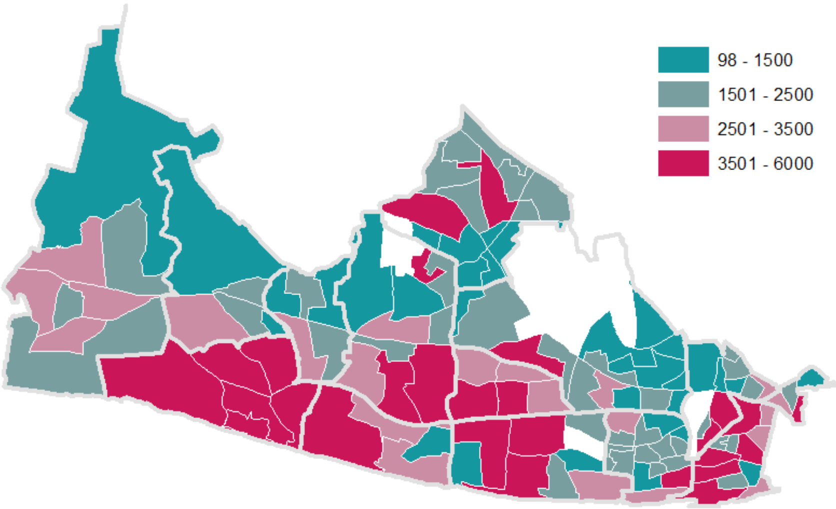


Figure 83: Illustration of total direct CO_2 Emissions in tons deriving from Heat Energy Use in the Statistical Areas of Altona (Author, 2018)

Total CO_2 emissions per Statistical Area vary from less than 100 t to 6,000 t. The pattern of geographical distribution has slightly changed in comparison with total energy use. The areas, which are provided with district heat by Vattenfall or are connected to the more carbon intense heating grids of HanseWerk Natur have higher CO_2 emissions relative to their energy consumption. Inversely, the northern part of Altona, which is connected to the less carbon intense grid “Verbund West”, and other areas provided by heat from Urbana have lower CO_2 emissions relative to their heat energy use.

[I] For natural gas, the emission factor for CO_2 and CO_2e is similar (Memmler et al., 2017, p. 80). To ensure compatibility with factors for district heat, the CO_2 emission factor is used. For the same reason only direct emissions are included. The emission factor includes the fuel utilization rate of 88 % and is calculated by dividing the direct CO_2 emission factor by the fuel utilization rate: 202 g CO_2/kWh / 0.88 = 230 g CO_2/kWh.

This change of pattern also shows in emissions per capita (cf. Figure 84). Generally, relative to heat energy use per capita, emissions are higher in the city centre and lower in the north. The amounts of emissions per capita show a great range from less than 1 t CO2 to over 3 t CO_2. Highest emissions are to be found in the southern parts of Altona, which are more urban in the east and more rural in the west. Some other Statistical Areas located further north also show high emissions.

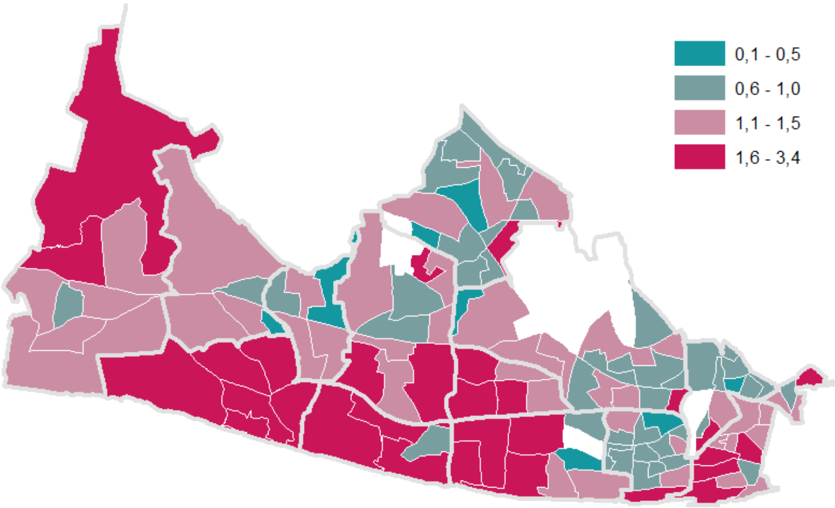


Figure 84: Illustration of direct CO_2 Emissions per Inhabitant (t/capita) deriving from Heat Energy Use in the Statistical Areas of Altona (Author, 2018)

4.7 Classification in the Context of Climate Scenarios and Goals

In sections 4.5.2 and 4.6.2 total energy consumption of electricity and heat energy were shown. The amounts of energy use can be divided by the living area to obtain an approximate amount of total energy use per square metre. The unit of heat energy per living area was used in several targets (cf. chapter 3.1) and is established as technical unit (cf. Appendix Q), which is why it is desirable to have an inventory in the same unit at the local level. The obtained results for Altona can easily be compared to existing goals.

Uncertainties in data on heat energy use were explained in section 4.6.1 and on the calculation of living area at the level of Statistical Areas in section 4.2.8 and Appendix G. The uncertainties lead to inaccuracies, but the procedures currently represent the most accurate way possible of receiving a picture on heat energy use and living area with the given data. The result should not be seen as exact analysis but as indicator to assess the current situation and to decide on further action to reach set goals.

Figure 85 shows the result of such a comparison. Only few Statistical Areas reach Hamburg's goal for 2050 of residential energy use below 55 kWh/m² (cf. section 3.1.4). The national limit for a nearly-climate neutral building stock was 74 kWh/m² to 104 kWh/m² (cf. section 3.1.3). A few more Statistical Areas comply with the limit of 104 kWh/m². The areas coloured in light red stayed below today's national average of energy consumption of 170 kWh/m² (cf. section 3.1.3). All areas coloured in dark red exceeded the national average.

The categorization can help to estimate, where certain goals are realistically achievable. Areas coloured in light green for example can realistically reach Hamburg's goal of less than 55 kWh/m² heat energy use, while areas coloured in dark red should first aim to get below the current national average. In return, other areas would then have to enforce even more ambitious reductions to balance out Altona's average.

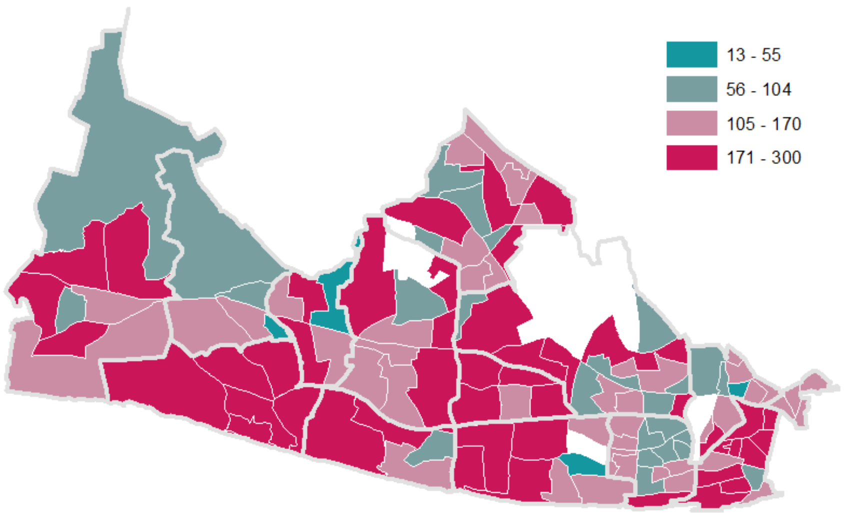


Figure 85: Illustration of Heat Energy Use in kWh per Living Area m² in the Statistical Areas of Altona (Author, 2018)

Annual CO_2 emissions per inhabitant resulting from electricity and heat energy use separately were already presented in sections 4.5.4 and 4.6.4. The inaccuracies involved were explained before. The sum of both is shown in Figure 86. In some areas, people emit less than 1 t of CO_2 per year. In several other areas however, mostly in the west and south, but also in the city centre, emissions exceeded 2 t per capita. The target globally and in Hamburg for 2050 is a limit of total emissions per capita to 2 t annually (cf. 2.5.5). This amount is currently emitted in the dark red areas by residential buildings alone. Sharp reduction measures are consequently needed to bring emissions down to a desirable level.

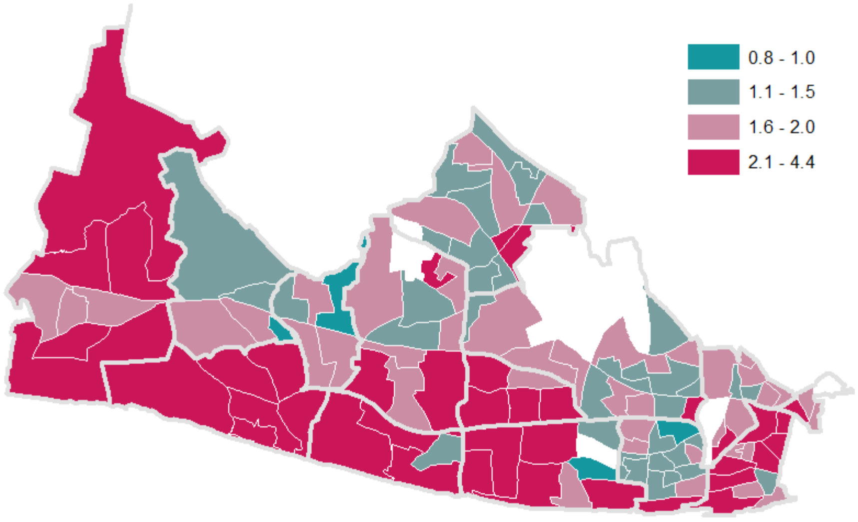


Figure 86: Illustration of total CO_2 Emissions per Inhabitant resulting from Electricity and Heat Energy use in the Statistical Areas of Altona (Author, 2018)

The unit of emission per capita helps to express the climatic impact at a personal level. It is essentially the same as what is generally known as carbon footprint. It includes both energy use and carbon intensity, which are the two adjustment methods in mitigation action. Planners and policy makers of Altona have confirmed that when residents are the target group of such depictions to tackle individual action, the carbon footprint is generally the most useful unit to work with (cf. interviews in Appendix O, Appendix P and Appendix Q and Gottschick, 2018). Even though the inclusion of GHG other than CO_2 would be more meaningful (Gottschick, 2018), the difference between CO_2 and CO_2e is negligibly small (cf. Memmler et al, 2017, pp. 43, 80). However, it should be clear that due to the lack of information on electricity suppliers, the indication of CO_2 per capita cannot show the exact amount or the effect of a shift to a different supplier. In some cases it can therefore be more useful to use the more exact unit of energy use per capita (cf. Appendix O).

Before deciding for or against a unit to work with, the message to be transmitted should be clear. In this paper, the focus is on energy use in relation to set climate goals as well as its climatic impact. This is why results were presented in kWh/m² and t CO_2/capita. Both illustrations have demonstrated the urgent need of mitigation action.

5 Correlations with Energy Use

Understanding energy consumption is a key element in order to make use of potentials for reduction. For this purpose, existing studies about the influences of technical equipment and user behaviour were examined before (cf. 3.3.6). For the authorities of a city or a borough like Altona the question remains if the proven influences also exist on a larger level. Can certain demographic characteristics indicate high energy consumption? Since consumption data is hard to obtain, and not always available, this could be a new approach to identify areas with high energy consumption.

Subsequently, correlations between the characteristics of the borough Altona as shown above and its energy use are calculated. The program that is used for this purpose is ‘R’. It is important to note that ideally, more indicators and indicators with fewer uncertainties would be used. However, in this case study as well as probably in most other cases, available data is limited. This analysis is a trial, if interdependencies can be proven within the limitation given by data availability.

The used data refers to the year 2015. The study is therefore cross-sectional. If it was replicated for several years, it would be a longitudinal analysis, indicating developments over time. Instead, this paper focuses on only the year 2015 and works out existing interdependencies for the year. Additionally it should be noted, that the study does not only rely on samples, but data on the entire borough. The areas, which had to be excluded, are explained in the text. Results are therefore representative for the entire borough. It will later on be discussed, if it can also be representative for larger areas.

5.1 Models

Two analyses are made: one for the consumption of electricity and one for the consumption of heat energy. The model for both analyses is the same.

5.1.1 Statistical Indicators

To understand the statistical analysis, a few terms are explained beforehand.

Number of observations

The analysis includes all data of the borough Altona, not just samples. The number of observations is therefore defined by the division of the borough in smaller areas.

The division was made according to the Statistical Areas, of which there are 131 in the borough. The values of the variables were determined for everyone of these areas. However, some Statistical Areas were excluded from the analysis. Either the given energy use was incomplete, or it was exceptionally high. The names of these areas as well as the reason for their exclusion are given in Appendix H and Appendix I. The model for the analysis of electricity use is left with 126 Statistical Areas and the model for the analysis of heat energy use is left with 121.

Two variables (X_{07b} and X_{15}[l]) are only available at the level of districts, of which there are 14 in the borough. The number of observations for these two variables is therefore decreased to only 14. Here, all data was aggregated from the level of Statistical Areas to the level of districts, so that the statistical analysis could still be performed.

The merge of data reduces the range of values, since extreme values are compensated by values closer to the mean. The comparison of values on both levels has mostly shown higher correlations on the district level, but always lower significance of the models (cf. Appendix K). Additionally, inaccuracies in certain Statistical Areas could not be excluded since the only option would be the exclusion of an entire district, reducing the number of observations even further. Consequently, the higher level of districts with the smaller number of observations is less preferable and therefore only applied when it is the only option.

Simple and multiple linear regression

Regression is the relation of a variable to another. The variable, which depends on the other, is called dependent variable or response Y, while the other variable is the independent variable or regressor X (Wonnacott & Wonnacott, 1990, p. 358).

In a linear regression the relation can be expressed by a straight fitting line (definition see below), while nonlinear regressions show patterns of nonlinear functions such as exponential functions (ibid., p. 452). As opposed to simple linear regression models, multiple linear regression models include several independent variables and analyse the relation with the dependent variable. The advantage is a reduction in the bias of so-called confounding variables (ibid., pp. 397, 428).

Expressing linear regression models

In the simple linear regression analysis the correlation of every Y and X is looked at. The goal is to find a fitting line with the equation Y = a + bX (Brosius, 2013, p. 544; Wonnacott & Wonnacott, 1990, p. 360). The factor 'b' describes the slope of the fitting line and expresses changes in Y when X is changed by a unit (ibid., p. 362). The intercept is quantified by 'a' and shows the amount of Y when X is zero. The fitting line itself is descriptive. It shows correlation but does not express causality. It can be visualised in scatterplots.

Since a multiple linear regression model includes several independent variables, it is difficult to visualize it in a two-dimensional graph. The model can be expressed with the equation Y = a + b1X1 +

[l] The variables are explained further in section 5.1.3.

$b_2X_2 + b_3X_3 + \ldots$ (Brosius, 2013, p. 564). ‘a’ represents the intercept and the ‘b’ values can geometrically be interpreted as the slope of the corresponding X when all other X are constant (ibid., p. 401).

The coefficient ‘r’

The regression analysis expresses through the fitting line how X and Y are related. Yet, in order to quantify the degree of relation, correlation needs to be analysed. It is given by the coefficient ‘r’. (Brosius, 2013, p. 520; Wonnacott & Wonnacott, 1990, pp. 475-476). It can take any value from -1 to +1. The sign indicates the direction of the correlation (Wonnacott & Wonnacott, 1990, p. 479), just as the sign of the slope did. A positive sign means that both X and Y change the same way. An increase in X for example leads to an increase in Y. A negative sign means the opposite, so an increase of X for example leads to a reduction in Y.

In addition, the absolute value of the r-value expresses the strength of a correlation (Brosius, 2013, p. 521). While thresholds for the strength can be very detailed (for example Brosius, 2013, p. 523), in this analysis the following thresholds are used: An absolute value below 0.3 indicates a weak correlation, an absolute value above 0.7 a strong correlation and anything in between can be understood as a moderate correlation.

r-value	-1.0	-0.7	-0.3	0.0	0.3	0.7	1.0
strength	strong	moderate	weak	weak	moderate	strong	

Table 5: The coefficient 'r' expressing the strength of a correlation (Author, 2018)

Two things need to be kept in mind. First of all, the coefficient ‘r’ is only an indicator for linear correlation. Other correlations such as quadratic ones are not expressed (Brosius, 2013, p 521). Secondly, it is important to note that the relation does not automatically indicate cause and effect. It could also show the influence by a confounding variable (Brosius, 2013, p. 523). This phenomenon is called a “spurious” or “nonsense” correlation (Wonnacott & Wonnacott, 1990, p. 488). Nevertheless, any correlation can be an insightful knowledge. It might not show the cause of energy use, but it could serve as a future indicator for energy consumption when consumption data itself is not available.

The value r^2

Another important variable is ‘r^2’. It is the square of the correlation coefficient r and can also be called “coefficient of determination”. It expresses the share of variances of Y, which can be explained by the model (Brosius, 2013, p. 554; Wonnacott & Wonnacott, 1990, p. 487). Just like the r-value itself, when r^2 is 1, the regression line explains the observations by 100 %, while an r^2 of 0 indicates that there is no linear relation between X and Y (ibid., p. 487).

Regarding multiple linear regression analyses, it could be assumed, that the more independent variables are included in a model, the higher the r^2. To avoid this assumption, the so-called 'adjusted r^2' takes into account the number of variables. When the corrected r^2 is lower in the multiple linear regression analysis than in the simple linear regression analysis, it indicates that the added independent variables did not improve the model (Brosius, 2013, p. 567).

The p-value

The p-value expresses the error probability (in German: Irrtumswahrscheinlichkeit) (Brosius, 2013, p. 524) and is therefore an indicator of significance. It is given for the intercept 'a' and the factor(s) 'b'. The p-value of 'b' helps to decide when to reject the null hypothesis, which implies that there is no statistical significance of X influencing Y (Wonnacott & Wonnacott, 1990, pp. 291, 293, 382). "The p-value summarizes very clearly how much agreement there is between the data and [the null hypothesis]" (ibid., p. 294). Usually the null hypothesis is rejected when the p-value is below 0.05 (Brosius, 2013, p. 486, Wonnacott & Wonnacott, 1990, p. 301). In other words, a low p-value supports the significance of the model. In multiple linear regression models p-values are given for every regressor individually and for the model itself. The significance should however not be confused with the strength of correlation (Brosius, 2013, p. 524).

In accordance with the estimates given by the statistic program RStudio, the following thresholds are used in this analysis: A p-value below 0.001 indicates a very high significance, below 0.01 a high significance and below 0.05 a moderate significance. When the p-value is higher than 0.05, significance can be excluded (Brosius, 2013, p. 486).

p-value		0.001	0.01	0.05
significance	very high	high	moderate	no

Table 6: The p-value determining the error probability and thus expressig significance (Author, 2018)

Interpretation of a model

Based on previous explanations, the following factors increase the importance of a model:

- a high level of correlation (high r-value)
- a high level of determination (high r^2-value)
- a high level of significance (low p-value) and
- plausibility of the influence of a variable, which refers mainly to the direction of correlation, expressed by the sign of the slope (Brosius, 2013, p. 567).

5.1.2 Dependent Variables

Every model has one dependent variable, also called response variable. In this analysis two dependent variables are examined. The first one is Y01 and describes electricity use per inhabitant. All associated models can be found in section 5.2. The second response variable is Y02. It quantifies heat energy use per inhabitant. The analyses of Y02 are conducted in section 5.3. Background information on the compilation of data was given in sections 4.5 and 4.6.

Variable	Description
Y_{01}	Electricity use per inhabitant in 2015 [kWh]
Y_{02}	Heat energy use per inhabitant in 2015 [kWh]

Table 7: The dependent Variables Y_{01} and Y_{02}

5.1.3 Independent Variables

Several regressors are included in both analyses. They concern the characteristics presented in section 4 and are listed in the tables below.

Variable	Description
X_{01}	Inhabitants per household
X_{02}	Inhabitants per hectare
X_{03}	Share of single person households
X_{04}	Households per building
X_{05}	Households per hectare
X_{06}	Gross floor area per area of Statistical Area
X_{07}	Gross floor area per inhabitant
X_{08}	Share of households with children
X_{09}	Share of people ≥65 years old
X_{10}	Employment rate
X_{11}	Unemployment rate
X_{12}	Share of social housing
X_{13}	Average number of storeys
X_{14}	Average AV ratio

Table 8: The independent Variables X_{01} to X_{14}

Since characteristics such as “average building age” fail to express the implication for every building era, having several independent variables, which describe the building age, gives more detailed information.

Variable	Description
X_{age1}	Share of buildings erected before 1918
X_{age2}	Share of buildings erected from 1919 to 1948
X_{age3}	Share of buildings erected from 1949 to 1957
X_{age4}	Share of buildings erected from 1958 to 1968
X_{age5}	Share of buildings erected from 1969 to 1978
X_{age6}	Share of buildings erected from 1979 to 1983
X_{age7}	Share of buildings erected from 1984 to 1994
X_{age8}	Share of buildings erected after 1995

Table 9: The independent Variables X_{age1} to X_{age8}

The same thing applies for the building typology. To find out the influence of a certain typology, it is useful to have the share of every typology in all buildings and calculate each correlation.

Variable	Description
X_{typ1}	Share of single family/semi-detached houses
X_{typ2}	Share of terraced houses
X_{typ3}	Share of apartment buildings (detached)
X_{typ4}	Share of apartment buildings (group house)
X_{typ5}	Share of apartment buildings (block)
X_{typ6}	Share of apartment buildings (high-rise)

Table 10: The independent Variables X_{typ1} to X_{typ6}

When the independent variables are not actually independent but correlate with one another, it is called multicollinearity. A model is only useful when every regressor adds a new piece of information. This is impossible when the regressors correlate strongly with one another. Logically, the shares of elderly people, children, employed and unemployed people are all related in a way. When their statistic correlation is at least $r = 0.70$, variables are assigned to one group. Only one variable of every group is later used in a multiple linear regression model. Preferably, for the multiple linear regression analysis, a variable is selected, which is easy to obtain and obtains only few uncertainties. This is supposed to facilitate replicability of the model. The following tables therefore also explain the accessibility of the variables.

The first group consists of X_{01} (inhabitants per household), X_{03} (share of single person households) and X_{08} (share of households with children). All three correlate strongly with one another. All of them are easily obtained (cf. Table 11).

Variable	Key Point	Accessibility
X_{01}	Inhab/hh	The variable is calculated by dividing two indicators: The number of inhabitants in private households is not part of the social indicators, but is also tracked by the authorities in Hamburg (cf. Kaiser, 2018; Appendix E). The number of households is published as part of the social indicators.
X_{03}	Single P hh	Published annually as part of the social indicators
X_{08}	children	Published annually as part of the social indicators
All three variables are easily obtained. The variable with the highest significant correlation in the simple linear regression analysis will be selected for the multiple linear regression models.		

Table 11: Accessibility of the correlating regressors X01, X03 and X08

The second group of strongly correlated variables is that of X_{02} (inhabitants per hectare), X_{05} (households per hectare), X_{06} (GFA per area) and X_{typ4} (grouped apartment buildings) (cf. Table 12).

Variable	Key Point	Accessibility
X_{02}	Inhab/ha	The variable is calculated by dividing two indicators: The number of inhabitants (as explained in Table 11), and The size of an area: Published annually as part of the social indicators, but to be more specific can be calculated with the help of ALKIS (cf. section 4.1)
X_{05}	HH/ha	The variable is calculated by dividing the number of households by the size of an area (both explained above)

Variable	Key Point	Accessibility
X_{06}	GFA/area	Difficult to calculate, includes high uncertainties (cf. section 4.2.7)
X_{typ4}	MFH group	Difficult to obtain, includes high uncertainties (cf. section 4.4.5)
Due to accessibility and uncertainties, X_{06} and X_{typ4} will be excluded from multiple linear regression analyses. Either X_{02} or X_{05} will be used in the multiple linear regression analyses.		

Table 12: Accessibility of the correlating regressors X02, X05, X06 and Xtyp4

The last group concerns X_{04} (households per building), X_{13} (number of storeys) and X_{14} (A/V ratio). They all include high uncertainties (cf. Table 13).

Variable	Key Point	Accessibility
X_{04}	HH/Building	The variable is calculated by dividing two indicators. The number of households is easily obtained (as described above). The number of buildings depends on assumptions made for the selection in ALKIS (cf. Appendix B).
X_{13}	No of Storeys	The number is taken from ALKIS, which is very vague.
X_{14}	AV ratio	The value is inaccurate since the calculation is based on very approximate assumptions (cf. Appendix C).
All variables include high uncertainties. The least uncertainties and the highest replicability are probably involved in the selection of residential buildings, which is why X_{04} is chosen over X_{13} and X_{14}.		

Table 13: Accessibility of the correlating regressors X04, X13 and X14

It is important to note that employment and unemployment rate statistically do not correlate highly with one another (r = 0.19). They can therefore both be included in the same model.

Multicollinearity is also too high among the regressors of building age and type, since the sum of all shares is always 100 %. When they are combined in one model, the calculations cannot be followed through (Brosius, 2013, p. 581). It is consequently impossible to create a model of multiple linear regression, which includes all X_{age} or all X_{typ}. As the simple regression analysis will show, only very few correlate significantly with energy use. Only these few will then be included in the multiple regression analysis.

As explained before, two variables were only available on the larger level of districts, which leads to a decrease in number of observations. This concerns living area (X_{07b}) and income (X_{15}) per person (cf. Table 14). They are still analysed, since both provide useful information. X_{07b} is thematically related to X_{07}, but since calculations on X_{07} included high inaccuracies, X_{07b} is likely to be more accurate. X_{15} gives information on annual income, which has not been included in the regressors yet. Both correlate so highly with one another (r = 0.95), that they are close to a perfect correlation of r = 1.00. meaning that they cannot be used in the same model.

Variable	Description
X_{07b}	Living area per inhabitant
X_{15}	Annual income per taxable person [€]

Table 14: The independent Variables X_{07b} and X_{15}

Even though X_{07b} and X_{15} are only analysed separately and because of the different levels will not be combined with any of the previous variables, multicollinearity is still looked at briefly. It will give a better understanding of the implications of X_{07b} and X_{15}, which is important in the evaluation.

When previous variables are aggregated at the level of districts, X_{07b} and X_{15} both correlate strongly positively ($r \geq 0.70$) with X_{07} (GFA per inhabitant), X_{typ1} (share of single family houses) and X_{typ3} (share of detached apartment buildings). Both correlate strongly negatively ($r \leq -0.70$) with X_{10} and X_{11} (employment and unemployment rate), X_{12} (share of social housing) and X_{typ5} (share of apartment buildings arranged in blocks). These relations will be discussed in the evaluations of the analyses.

5.2 Data Analysis for Electricity Use

Data on electricity consumption in Altona is analysed by means of linear regression analyses. First, a simple linear regression analysis is conducted, examining the relation of several factors individually on electricity consumption. The relations are presented in tables and scatterplots. Additionally, several multiple regression analyses are made. They include several influencing factors at the same time. The aim is to find a composition of influencing factors, which indicate electricity consumption in the most accurate manner possible.

5.2.1 Simple Linear Regression Analysis

The following table presents the calculated statistical indicators of every independent variable X. The correlation is given by the r-value and moderate correlations are highlighted. The coefficient of determination r² is also given. Last, the significance is expressed by the p-value. When there is significance, the cells are highlighted.

X	Key point	Correlation r		R^2	Significance p	
X_{01}	inhab/hh	0.21	weak	4.57 %	0.016	moderate
X_{02}	inhab/ha	-0.35	moderate	11.96 %	0.000	very high
X_{03}	single p hh	-0.24	weak	5.93 %	0.006	high
X_{04}	hh/building	-0.33	moderate	11.00 %	0.000	very high
X_{05}	hh/ha	-0.32	moderate	10.18 %	0.000	very high
X_{06}	GFA/area	-0.27	weak	7.24 %	0.002	high
X_{07}	GFA/inhab	0.55	moderate	19.88 %	0.000	very high
X_{08}	children	0.06	weak	0.41 %	0.476	no
X_{09}	≥65 yrs	0.44	moderate	19.27 %	0.000	very high
X_{10}	employm.	-0.54	moderate	28.60 %	0.000	very high
X_{11}	unempl.	-0.43	moderate	18.86 %	0.000	very high
X_{12}	social h.	-0.25	weak	6.22 %	0.005	high
X_{13}	N° storeys	-0.29	weak	8.68 %	0.001	very high
X_{14}	AV ratio	0.25	weak	6.10 %	0.005	high
X_{age1}	…-1918	0.08	weak	0.62 %	0.380	no
X_{age2}	1919-1948	0.20	weak	4.03 %	0.024	moderate
X_{age3}	1949-1957	0.06	weak	0.34 %	0.519	no

X	Key point	Correlation r		R^2	Significance p	
X_{age4}	1958-1968	-0.08	weak	0.60 %	0.387	no
X_{age5}	1969-1978	-0.20	weak	3.81 %	0.029	moderate
X_{age6}	1979-1983	0.05	weak	0.27 %	0.565	no
X_{age7}	1984-1994	-0.02	weak	0.03 %	0.845	no
X_{age8}	1995-…	-0.02	weak	0.03 %	0.844	no
X_{typ1}	EFH/DHH	0.46	moderate	21.51 %	0.000	very high
X_{typ2}	RH	-0.05	weak	0.28 %	0.556	no
X_{typ3}	MFH single	0.38	moderate	14.06 %	0.000	very high
X_{typ4}	MFH group	-0.16	weak	2.59 %	0.072	no
X_{typ5}	MFH block	-0.39	moderate	15.32 %	0.000	very high
X_{typ6}	MFH high-r	-0.13	weak	1.71 %	0.144	no

Table 15: Results of Simple Linear Regression Analysis for Y_{01} and X_{01}-X_{typ6}

There are no strong correlations, since the r-value is always below 0.7. This can be explained by the fact that electricity use is influenced by far more than just one factor so that it is unlikely to correlate strongly with only one variable.

Most significant models (low p-value) have a higher correlation (high r-value) and coefficient of determination (high r^2) and therefore indicate a meaningful influence on Y. The associated X should therefore be considered as indicators for electricity consumption per capita. The sign of the r-value shows the direction of correlation and consequently whether the regressor indicates an increase or a decrease of electricity use. A more detailed evaluation for all significant regressors can be found in section 5.2.4.

According to the analyses, electricity use per capita rises with the number of people living in a household (X_{01} and X_{03}). However, common sense would define the effect the other way around. When people share electronic devices such as communication and entertainment devices, they should use less energy per person. There must be a reason why X_{01} correlates positively with electricity use. Possibly, other factors of urbanization are stronger than the effect of people per household.

The fact that both, the employment and the unemployment rate, indicate a decrease in electricity use seems irritating and contradicting. However, a look at section 4.3.2 can clear up the issue: The two variables are not complementary and do not correlate with one another. Areas with both a low employment and unemployment rate show high electricity consumption.

Additionally, analyses with a much smaller scope were made for two more independent variables. The data of living area X_{07b} and income X_{15} was only available at a level of districts, of which there are 14 in Altona. Both variables show a strong positive correlation with electricity use and reach a very high significance. A large living area and a high income consequently are very good indicators for high electricity use.

X	Key point	Correlation r		R^2	Significance p	
X_{07b}	liv.area/inh.	0.898	strong	80.57 %	0.000	very high
X_{15}	income/p.	0.858	strong	73.55 %	0.000	very high

Table 16: Results of Simple Linear Regression Analysis for Y01 and X_{07b} and X_{15}

It is essential to note that as shown in Appendix K, significance of all other variables was much higher for models on the level of Statistical Areas. Hardly any variables reached very high significance on the district level. This fact enhances the meaning of living area and income as indicator for electricity use.

In summary, the simple linear regression analyses have presented several variables, which can serve as indicators for electricity use. Indicators, which individually correlate significantly positively, meaning they indicate an increase of electricity use per capita, are:

- GFA and living area per inhabitant (X_{07} and X_{07b}),
- a high share of elderly people (X_{09}),
- annual income (X_{15}),
- single or semi-detached houses (X_{typ1}) and
- detached apartment buildings (X_{typ3}).

Factors correlating significantly negatively, indicating a decrease of electricity use, are:

- inhabitants per hectare (X_{02}),
- households per building and per hectare (X_{04} and X_{05}),
- employment rate as well as unemployment rate (X_{10} and X_{11})
- number of storeys (X_{13}) and
- apartment building blocks (X_{typ5}).

The strongest and truly meaningful results can be seen in living area per inhabitant (X_{07b}) and annual income (X_{15}). Despite the fact, that the data was only available on a district level, they can significantly explain electricity use by 81 % and 74 %.

5.2.2 Scatterplots

To visualise interdependencies, also non-linear ones, scatterplots can help (Brosius, 2013, p. 517). To prove that there are no non-linear patterns, all scatterplots need to be looked at. The ones without significance can be found in Appendix L. None of them show non-linear patterns, so it can be assumed that they do not correlate with electricity use, neither in a linear nor in a non-linear way.

First, the scatterplots of models with variables correlating significantly positively are shown.

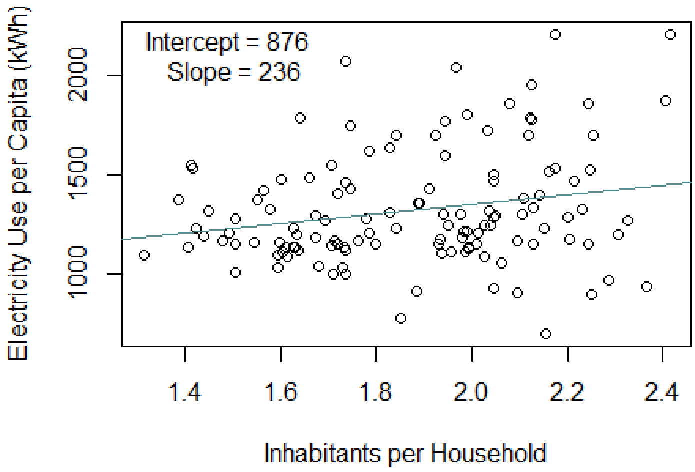


Figure 87: Scatterplot of Electricity Use per Capita (Y_{01}) and Inhabitants per Household (X_{01}) (Author, 2018)

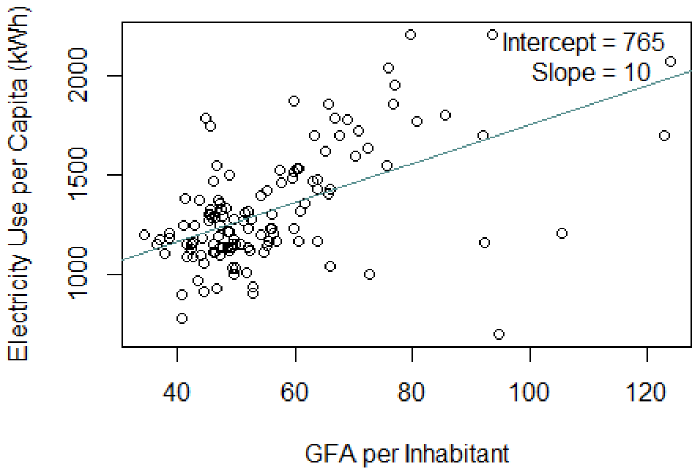


Figure 88: Scatterplot of Electricity Use per Capita (Y_{01}) and GFA per Inhabitant (X_{07}) (Author, 2018)

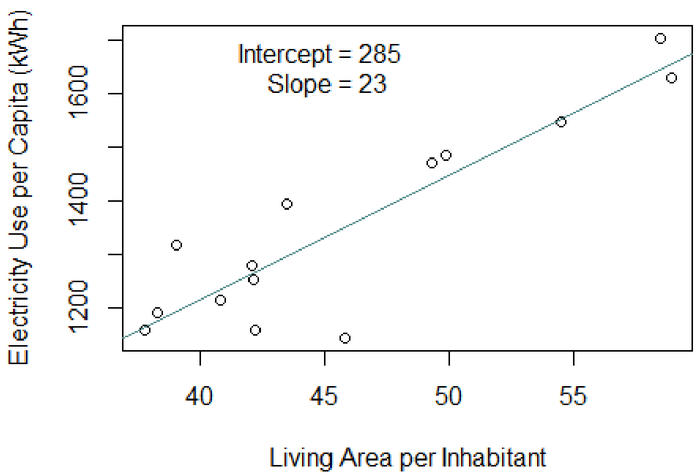


Figure 89: Scatterplot of Electricity Use per Capita (Y_{01}) and Living Area per Inhabitant (X_{07b}) (Author, 2018)

Figure 91: Scatterplot of Electricity Use per Capita (Y_{01}) and Elderly People (X_{09}) (Author, 2018)

Figure 90: Scatterplot of Electricity Use per Capita (Y_{01}) and A/V Ratio (X_{14}) (Author, 2018)

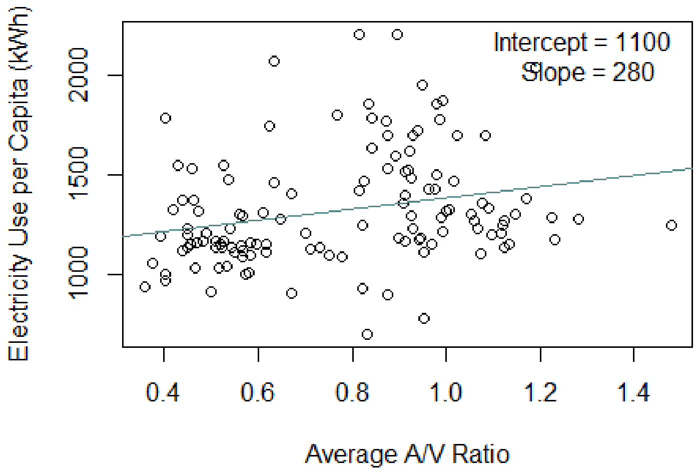
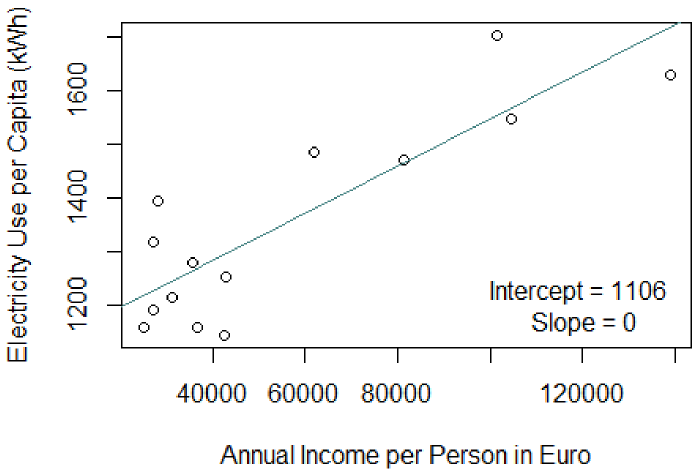


Figure 92: Scatterplot of Electricity Use per Capita (Y_{01}) and Annual Income (X_{15}) (Author, 2018)



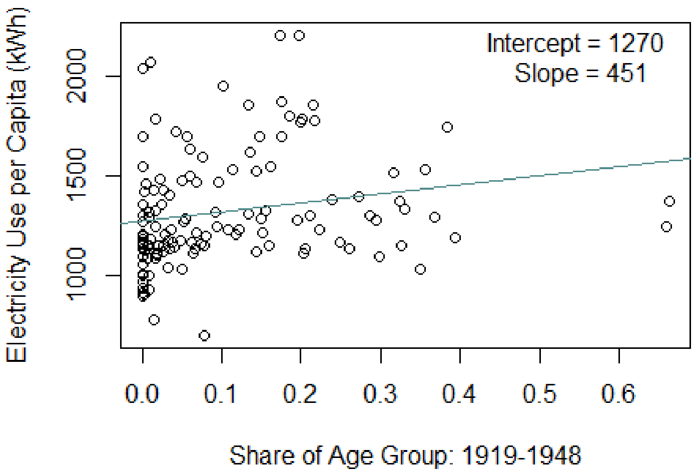


Figure 93: Scatterplot of Electricity Use per Capita (Y_{01}) and Building Age Group of 1919-1948 (X_{age2}) (Author, 2018)

Figure 94: Scatterplot of Electricity Use per Capita (Y_{01}) and Single or Semi-Detached Houses (X_{typ1}) (Author, 2018)

Figure 95: Scatterplot of Electricity Use per Capita (Y_{01}) and Detached Apartment Buildings (X_{typ3}) (Author, 2018)

A look at the scatterplots explains why correlations are not stronger. Even though tendencies can be seen, the independent variables are not perfect indicators for electricity use. There are many exceptions. An abnormality can be seen in the scatterplot of elderly people. The fitting line is very likely to be influenced by the outlier with an abnormally high share of elderly people. To gain further knowledge on this influence, future analyses taking a closer look at excluding such outliers can be recommended.

The clearest correlation with electricity use can be seen in living area and income. Both seem to be very good indicators for electricity use. A presumption for the fact that the number of people living in a household seems to increase electricity use was given in section 5.3.1.

Next, the scatterplots of all models with variables correlating negatively and at least moderately with electricity use are shown.

Figure 98: Scatterplot of Electricity Use per Capita (Y_{01}) and Inhabitants per Hectare (X_{02}) (Author, 2018) (Author, 2018)

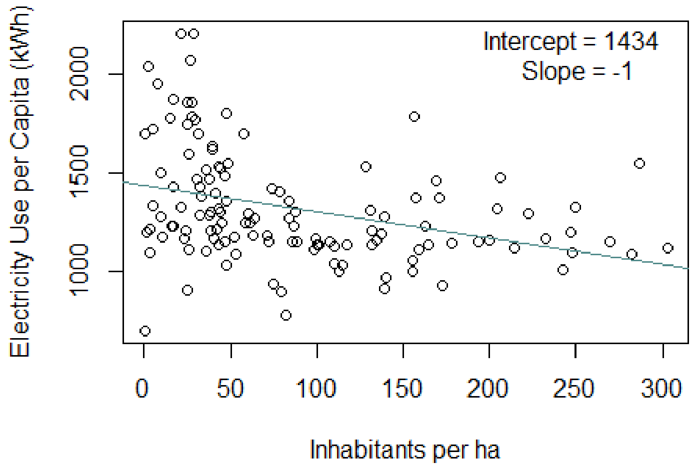
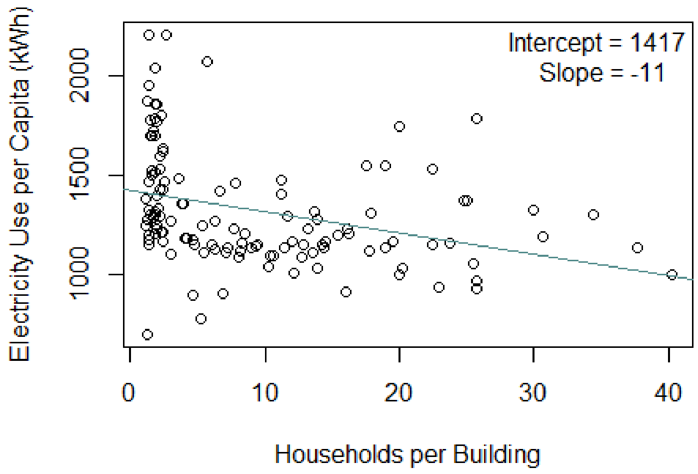


Figure 97: Scatterplot of Electricity Use per Capita (Y_{01}) and Single Person Households (X_{03}) (Author, 2018) (Author, 2018)

Figure 96: Scatterplot of Electricity Use per Capita (Y_{01}) and Households per Building (X_{04}) (Author, 2018) (Author, 2018)



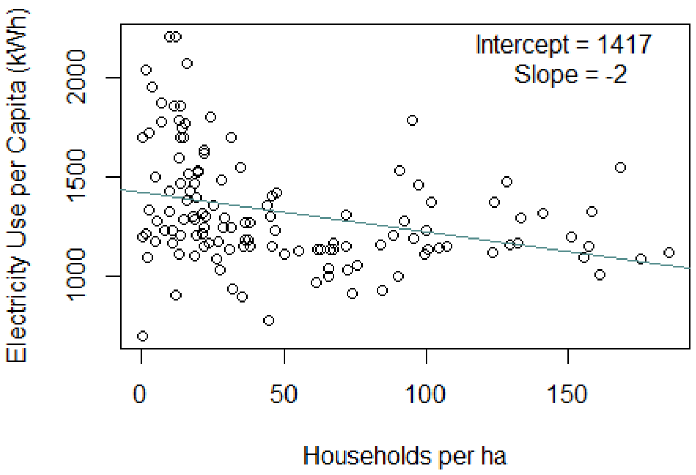


Figure 101: Scatterplot of Electricity Use per Capita (Y_{01}) and Households per Hectare (X_{05}) (Author, 2018)

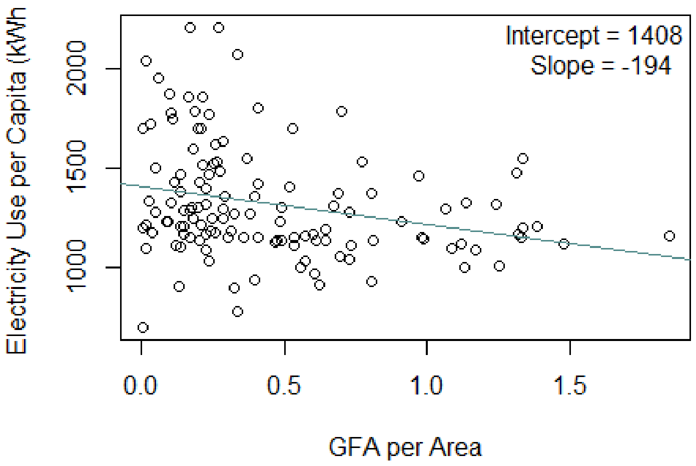


Figure 100: Scatterplot of Electricity Use per Capita (Y_{01}) and GFA per Area (X_{06}) (Author, 2018)

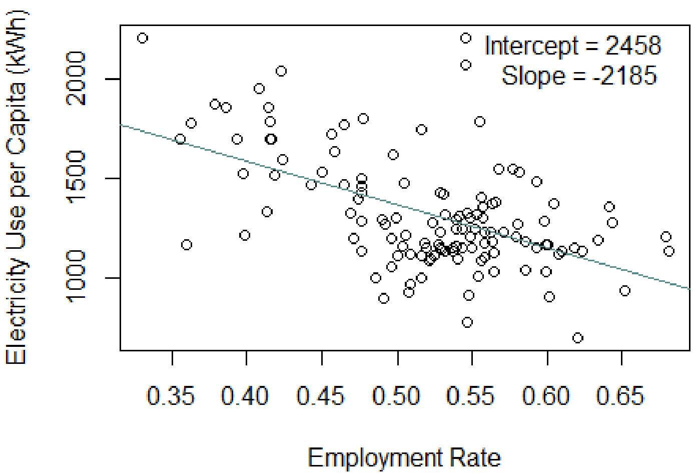


Figure 99: Scatterplot of Electricity Use per Capita (Y_{01}) and Employment Rate (X_{10}) (Author, 2018)

Figure 104: Scatterplot of Electricity Use per Capita (Y_{01}) and Unemployment Rate (X_{11}) (Author, 2018)

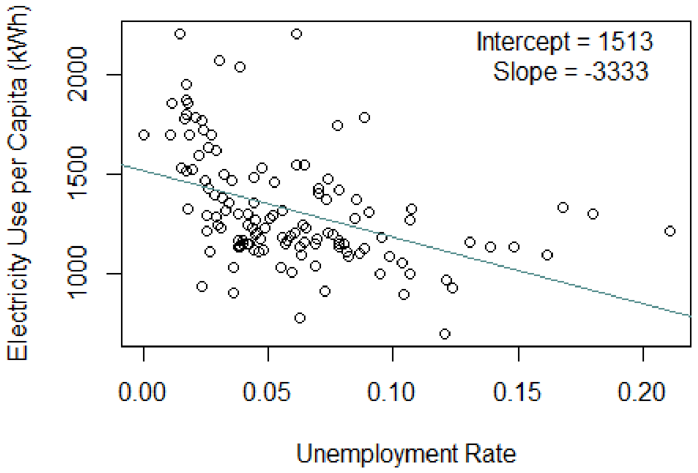


Figure 103: Scatterplot of Electricity Use per Capita (Y_{01}) and Social Housing (X_{12}) (Author, 2018)

Figure 102: Scatterplot of Electricity Use per Capita (Y_{01}) and Number of Storeys (X_{13}) (Author, 2018)

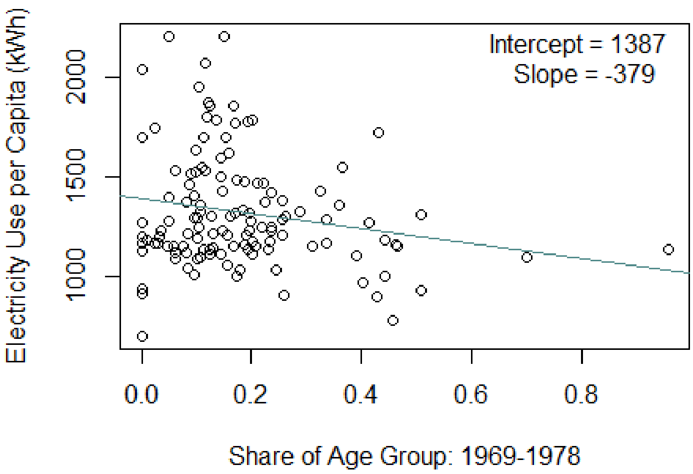


Figure 105: Scatterplot of Electricity Use per Capita (Y_{01}) and Building Age Group 1969-1978 (X_{age5}) (Author, 2018)

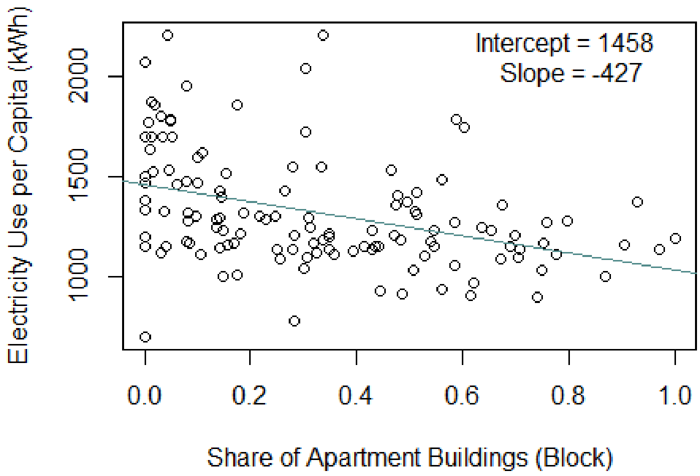


Figure 106: Scatterplot of Electricity Use per Capita (Y_{01}) and Apartment Buildings (Block) (X_{typ5}) (Author, 2018)

Just like positively correlated variables, the scatterplots of models with negative correlations visualize the moderate correlations. All observations are located rather loosely around the fitting line, explaining why calculated correlations are not stronger.

The fact that a high share of single person households is supposed to indicate a decrease in electricity consumption seems incomprehensible. This was discussed in section 5.2.1 already.

The surprisingly similar directions of correlation of both employment and unemployment rate are clearly to be seen in the scatterplots. The effect is not based on a few abnormalities and can therefore not be denied. Possible explainations are discussed in the following evaluation.

5.2.3 Multiple Linear Regression Analysis

Since energy use is influenced by several factors, a multiple linear regression analysis is made. There are far more factors influencing energy use, but due to data availability the analysis is limited to the ones named before.

To select the independent variables, which are used in the multiple linear regression analysis, results from the simple linear regression analysis in section 5.2.1 are looked at. Only the ones with significant correlations are included. In a second step, variables are excluded if they correlate with one another as described in section 5.1.3. Among the groups from Table 11, Table 12 and Table 13 only the ones, which are easy to obtain and show the highest correlation, are included. This leaves the multiple linear regression analysis with the variables as shown in Table 17.

X	Key point	Slope	Significance p	
Intercept: 1801; R^2: 52.02 %			0.000	very high
X_{02}	inhab/ha	-0.5	0.280	no
X_{03}	single p hh	91.6	0.686	no
X_{04}	hh/building	2.3	0.497	no
X_{07}	GFA/inhab	6.2	0.000	very high
X_{09}	≥65 yrs	228.4	0.390	no
X_{10}	employm.	-1586.0	0.000	very high
X_{11}	unemploym.	-1717.4	0.007	high
X_{12}	social h.	-50.3	0.790	no
X_{age2}	1919-1948	402.7	0.016	moderate
X_{age5}	1969-1978	-140.8	0.326	no
X_{typ1}	EFH/DHH	20.0	0.887	no
X_{typ3}	MFH single	-61.0	0.758	no
X_{typ5}	MFH block	46.9	0.696	no

Table 17: Results of the Multiple Linear Regression Analysis for Y_{01} and all significant regresors from X_{01}-Xt_{yp6}

The table also shows the results of the analysis. The multiple linear regression model has a very high significance and can explain over 50 % of electricity consumption. The sign of the slope of every X shows whether the correlation is positive or negative. The value expresses the change in kWh of electricity use with every change in the unit of X. Within the model only few regressors have a significant influence.

When only the four significant variables of the previous model are selected for a reduced model, r² and significance can even be improved. This means, that the selection of regressors is optimal (cf. Table 18). As shown, the reduced model is left with only four variables: X_{07}, X_{10}, X_{11} and X_{age2}. These four variables together can explain over 50 % of electricity consumption.

X	Key point	Slope	Significance p	
Intercept: 1773; R^2: 53.74 %			0.000	very high
X_{07}	GFA/inhab	7.0	0.000	very high
X_{10}	employm.	-1508.6	0.000	very high
X_{11}	unemploym.	-1829.0	0.000	very high
X_{age2}	1919-1948	458.8	0.001	high

Table 18: Results of the reduced Multiple Linear Regression Analysis for Y_{01} and X_{07}, X_{10}, X_{11} and X_{age2}

The connection of every variable with electricity use is quantified by the slopes. According to the model, every square metre of GFA per inhabitant leads to additional 7 kWh of electricity use, while every percent of buildings erected between 1919 and 1948 indicates an increase of 5 kWh. One percent of employment rate indicates a 15 kWh and of unemployment rate of 18 kWh decrease in electricity use.

Assuming that for responsible authorities, it is easier to procure data of only one thematic area, thematic coherent variables are looked at in more detail.

When employment and unemployment are put together in a model, significances are very high. The model can explain nearly 40 % of electricity use. Both regressors correlate negatively with Y01 (cf. Table 19). In the reduced model from Table 18, the two variables X_{07} and X_{age2} were also included. This lead to an increase in the coefficient of determination, but since both variables are difficult to obtain, X_{10} and X_{11} could be sufficient for responsible authorities to predict tendencies of electricity use.

X	Key point	Slope	Significance p	
Intercept: 2474; R^2: 39.15 %			0.000	very high
X_{10}	employm.	-1918	0.000	very high
X_{11}	unemploym.	-2653	0.000	very high

Table 19: Results of the Multiple Linear Regression Analysis for Y01 and X_{10}-X_{11}

Regarding building age, only two variables on building age were significant in the simple regression analysis. Combined, they only show moderate significance and a very low r^2 of approximately 6 %. Despite the fact that it is not possible to include all variables of building age in one model (cf. section 5.1.3), even the use of only selected ones are therefore not a good indicator for electricity use (cf. Table 20).

X	Key point	Slope	Significance p	
Intercept: 1337; R^2: 5.69 %			0.010	moderate
X_{age2}	1919-1948	416	0.036	moderate
X_{age5}	1969-1978	-347	0.042	moderate

Table 20: Results of the Multiple Linear Regression Analysis for Y_{01} and X_{age2}-X_{age5}

Similarly, variables of building type cannot all be included in one model. But even the model including only the three variables, which showed significant correlations in the simple linear regression analysis, shows only moderate results. While the model itself shows a very high significance, this is mainly due to X_{typ1}, which represents the share of single family houses. In total, the model can explain a fourth of electricity consumption, but is only slightly above the coefficient of determination for X_{typ1} alone. The multiple linear regression model increases the informative value only slightly.

X	Key point	Slope	Significance p	
Intercept: 1236; R^2: 24.87 %			0.000	very high
X_{typ1}	EFH/DHH	329	0.002	high
X_{typ3}	MFH single	463	0.021	moderate
X_{typ5}	MFH block	-130	0.238	no

Table 21: Results of the Multiple Linear Regression Analysis for Y_{01} and X_{typ1}, Xtyp3 and Xtyp5

The two variables at the district level (income and living area) cannot be combined in one model, since they correlate with each other (cf. section 5.1.3).

5.2.4 Evaluation of Statistical Analyses

As shown in section 3.3.5, electricity is mainly used for cooking, dishwasher and laundry machines, cooling devices and entertainment devices. A smaller share is used for lighting and the generation of hot water. In consequence, a high amount of electricity use implies different possibilities: Either the number of devices is higher, or the devices are less efficient, or the devices are used more. Variables correlating with electricity use indicate that one or several of these possibilities is true. While causality cannot be proved, it is still worth discussing existing relations.

Regarding structural characteristics of residential buildings, building age did not show any significant correlation with electricity use in simple linear regression models. Building types can in a certain way serve as indicator. In areas with a high share of single family houses and detached apartment buildings electricity consumption tends to be high, while apartment blocks tend to indicate lower amounts of electricity use. Generally, electricity is low where buildings comprise of a high number of households.

While studies name the decreasing number of people sharing a household as a driver for energy use (cf. section 3.3.6), the case study could not prove such correlation. In contrast, a higher number of people per household in Altona indicates higher electricity consumption per person. Despite the fact that the preceding check did not prove strong correlations with density or GFA per person, the variable would logically need to be connected to another confounding variable. A possibility is the time of use. Possibly, people living alone are home less often, but this assumption needs to be proved. Without a confirmed explanation, it should not be used as indicator for electricity use.

Areas with a low number of inhabitants per household are characterized as urban and dense areas. Since electricity use is rather low in dense areas, the variables of inhabitants and households per hectare indicate low electricity use. The connection between density and electricity use is not clear. Possible linkages to utilization rate and less luxurious equipment are discussed later on. As another parameter of urbanization, calculated GFA per person serves as a strong indicator for electricity use. A person living in a large household consumes more electricity than a person in a smaller household. The correlation is even stronger for the exact living area per district. It is the strongest indicator of all, but unfortunately not available at a smaller level. It seems likely that a large living area leads to a higher number of electric devices, but this assumption cannot be proven here.

With regard to the socio-demographic structure of residents, the age of inhabitants can serve as indicator for electricity use. While the share of households with children has absolutely no relation with electricity use, neither positive nor negative, the share of households with people over 65 years implies a significantly higher electricity consumption. Several explanations could be true: Elderly people are likely to be home more often, but they might also have older, less efficient electric devices. The times of use are difficult to quantify, but according to Manuel Gottschick from OCF Consulting, they would be highly interesting for an assessment of energy use (2018).

The situation of employment and unemployment indicates electricity use very well. The surprising result of both correlating negatively with electricity use can be explained by two theories. The first idea relates to the third group of people between 15 and 65 years, which is neither employed, nor do they receive unemployment benefits. Interestingly, these are the areas with higher incomes. Here, electricity use per person is highest. By combining employment and unemployment in a model, this third group of people is in principle included as well. The second idea concerns user behaviours. Employed people are probably home less often and therefore use their electric devices less. Unemployed people on the other hand are probably provided with fewer financial resources and hence have fewer electric devices and try to save electricity. Both ideas are only speculations and cannot be proven true or false here. Either way, employment rate and the share of people receiving unemployment benefits put together can serve as a good indicator for electricity use.

The best results in a model are received when GFA per inhabitant and the share of buildings erected between 1919 and 1948 are added to employment and unemployment rate. Combined, the four parameters can explain over 50 % of electricity use. However, there is no plausible reason, why building age should influence electricity use when heating is excluded. The model should therefore be treated with caution.

In comparison with employment and unemployment, income alone can explain electricity use much better. Results were nearly as meaningful as for living area per person. Since they correlate severely with one another, it can be assumed that a high income leads to larger living areas. The chain of effects goes even further. As existing multicollinearity has shown (cf. section 5.1.3), people with high incomes and large living areas tend to live in single family houses or detached apartment buildings in less dense areas. They tend not to live in apartment blocks, social housing and are neither employed nor do they receive unemployment benefits. So most of the significant indicators can be traced back to income. In addition, as Jan Gerbitz from ZEBAU suggests, income probably influences the number and type of electric devices as well. Additional luxurious equipment such as a sauna or a pool clearly uses even more electricity (cf. Appendix P). A possible opposed trend is the relation between income and investment in energy efficient devices. If people with higher incomes tended to invest more in energy-efficient technology, this would present a mitigating influence on electricity consumption. A lack of prove does not allow an assessment of this speculation. In any case, income as indicator for electricity use therefore has an outreaching importance.

Concluding, the structure of buildings can serve only limitedly as indicator for electricity use. Factors of urbanization and population are much more meaningful. A high density, a small living area, a high rate of employment and unemployment, a small share of households with elderly people and a low income all separately indicate low electricity consumption. To predict electricity use at the level of Statistical Areas in the easiest way, it is best to combine employment rate and unemployment rate. At the level of districts, living area per person is an excellent indicator, explaining 80 % of electricity use. The variable would be even more meaningful if it was accessible at the level of Statistical Areas. However, living area and many other variables can be traced back to income, constituting it as the root of several indicators. The results clarify the fact that statistically electricity use rather depends on density and the characteristics of inhabitants than on structural conditions.

Living area and several other variables can be traced back to income.

5.3 Data Analysis for Heat Energy

Just like in the simple linear regression analyses for electricity use (Y_{01}), several analyses are made for heat energy use (Y_{02}). All regressors are first analysed individually and the results presented in scatterplots. In a second step several regressors are combined in multiple linear regression models.

5.3.1 Simple Linear Regression Analysis

The following table gives the correlation r, the coefficient of determination r² and the significance p of every independent variable X separately. Moderate and high correlations as well as existing significances are highlighted (cf. Table 22).

X	Key point	Correlation r		r²	Significance p	
X_{01}	inhab/hh	0.32	moderate	10.04 %	0.000	very high
X_{02}	inhab/ha	-0.43	moderate	18.31 %	0.000	very high
X_{03}	single p hh	-0.30	moderate	9.10 %	0.001	very high
X_{04}	hh/building	-0.45	moderate	19.92 %	0.000	very high
X_{05}	hh/ha	-0.42	moderate	17.66 %	0.000	very high
X_{06}	GFA/area	-0.33	moderate	11.07 %	0.000	very high
X_{07}	GFA/inhab	0.51	moderate	25.95 %	0.000	very high
X_{08}	children	0.16	weak	2.66 %	0.074	no
X_{09}	≥65 yrs	0.38	moderate	14.24 %	0.000	very high
X_{10}	employm.	-0.57	moderate	32.67 %	0.000	very high
X_{11}	unempl.	-0.39	moderate	15.27 %	0.000	very high
X_{12}	social h.	-0.35	moderate	12.07 %	0.000	very high
X_{13}	N° storeys	-0.37	moderate	13.97 %	0.000	very high
X_{14}	AV ratio	0.32	moderate	10.41 %	0.000	very high
X_{age1}	…-1918	0.14	weak	2.03 %	0.119	no
X_{age2}	1919-1948	0.01	weak	0.00 %	0.915	no
X_{age3}	1949-1957	0.02	weak	0.04 %	0.833	no
X_{age4}	1958-1968	-0.11	weak	1.21 %	0.230	no
X_{age5}	1969-1978	-0.10	weak	0.97 %	0.282	no

X	Key point	Correlation r		r^2	Significance p	
X_{age6}	1979-1983	0.11	weak	1.12 %	0.248	no
X_{age7}	1984-1994	-0.05	weak	0.26 %	0.575	no
X_{age8}	1995-…	0.03	weak	0.11 %	0.723	no
X_{typ1}	EFH/DHH	0.49	moderate	23.87 %	0.000	very high
X_{typ2}	RH	0.12	weak	1.41 %	0.195	no
X_{typ3}	MFH single	0.43	moderate	18.24 %	0.000	very high
X_{typ4}	MFH group	-0.19	weak	3.46 %	0.041	moderate
X_{typ5}	MFH block	-0.53	moderate	27.62 %	0.000	very high
X_{typ6}	MFH high-r	-0.08	weak	0.69 %	0.364	no

Table 22: Results of Simple Linear Regression Analysis for Y_{02} and X_{01}-X_{typ6}

Noticeably, no regressor of building age has any significant correlation with heat energy use. Also, there are no strong correlations, which again can be explained by the fact that heat energy consumption is influenced by many factors and not just a single one.

The controversial positive correlation of inhabitants per household (X_{01}) and negative correlation of single person households (X_{03}) was discussed in section 5.2.1 already. Common sense contradicts the idea that a high number of people sharing a household would increase heat energy use per person. There is probably a confounding variable, which influences the results.

Just like before, living area and income are analysed on the higher level. Again, both models show a very high significance, which means that both variables are good indicators for heat energy use. Both individually explain heat energy use by nearly 70 % (cf. Table 23). The value should be attached with great importance, since at the level of districts inaccuracies deriving from the data generation (cf. Appendix I) were not excluded. Without these inaccuracies the coefficient of determination would probably be even higher.

X	Key point	Correlation r		R^2	Significance p	
X_{07b}	liv.area/inh.	0.815	strong	66.39 %	0.000	very high
X_{15}	income/p.	0.836	strong	69.93 %	0.000	very high

Table 23: Results of Simple Linear Regression Analysis for Y02 and X07b and X15

Analysed separately, several independent variables have shown highly significant, moderate correlations with heat energy use. The ones with a positive correlation, meaning they indicate higher heat energy use, are:

- GFA and living area per inhabitant (X_{07} and X_{07b}),
- share of people over 65 years (X_{09}),
- AV ratio (X_{14}),
- annual income (X_{15}),
- single or semi-detached houses (X_{typ1}) and
- detached apartment buildings (X_{typ3}).

Variables indicating lower heat energy uses per capita are:

- inhabitants per hectare (X_{02}),
- households per building and per hectare (X_{04} and X_{05}),
- GFA per area (X_{06}),
- employment and unemployment rate (X_{10} and X_{11}),
- social housing (X_{12}),
- number of storeys (X_{13}) and
- apartment buildings (group and block) (X_{typ4} and X_{typ5}).

The results are similar with the ones for Y_{01}, but a few more variables are added. These concern mainly the compactness of a building (X_{13}, X_{14}). Generally, dense areas, small building units and a small GFA per person facilitate low heat energy uses.

Strongest correlations are to be seen in income and living area per person. These two should be regarded as very good indicators for heat energy use.

5.3.2 Scatterplots

Again, the scatterplots of the significant models are visualized. All other scatterplots can be found in Appendix M.

First, the models with positive correlations are shown.

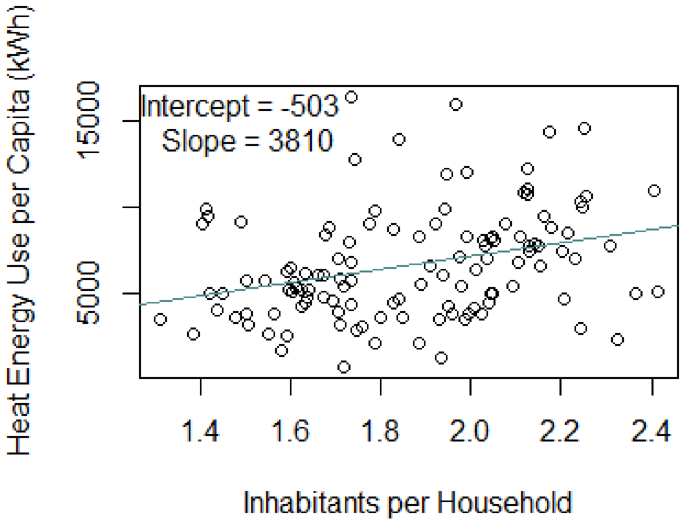


Figure 107: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Inhabitants per Household (X_{01}) (Author, 2018)

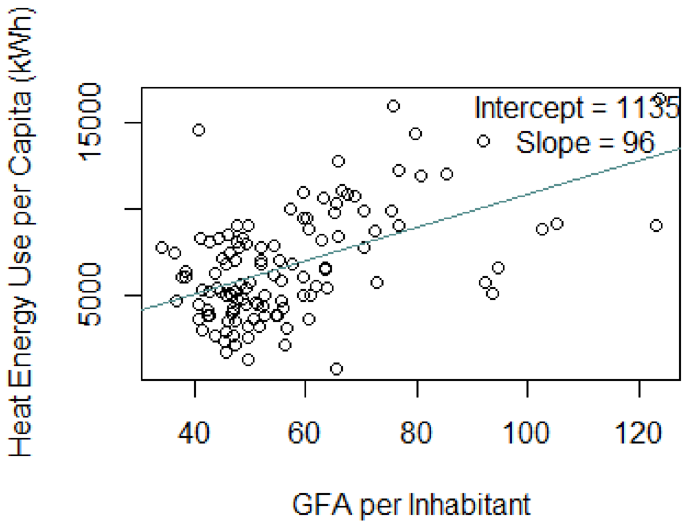


Figure 108: Scatterplot of Heat Energy Use per Capita (Y_{02}) and GFA per Inhabitant (X_{07}) (Author, 2018)

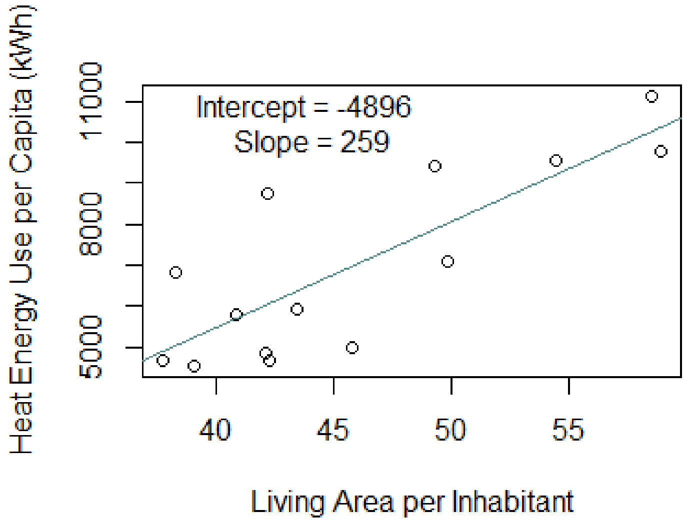


Figure 109: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Living Area per Inhabitant (X_{07b}) (Author, 2018)

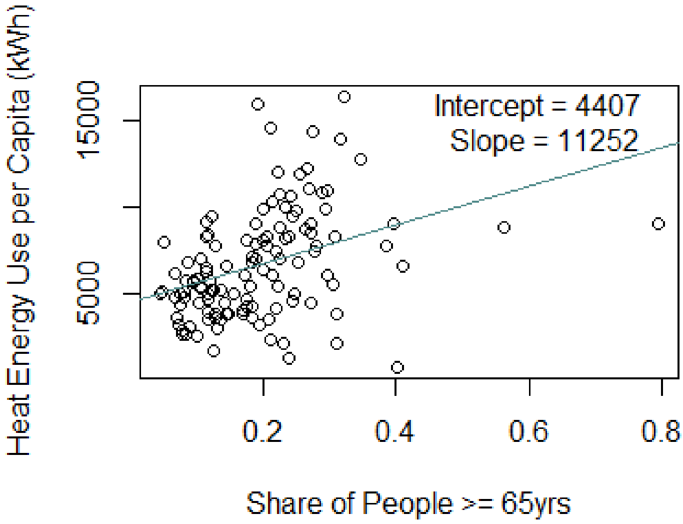


Figure 110: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Share of Elderly People (X_{09}) (Author, 2018)

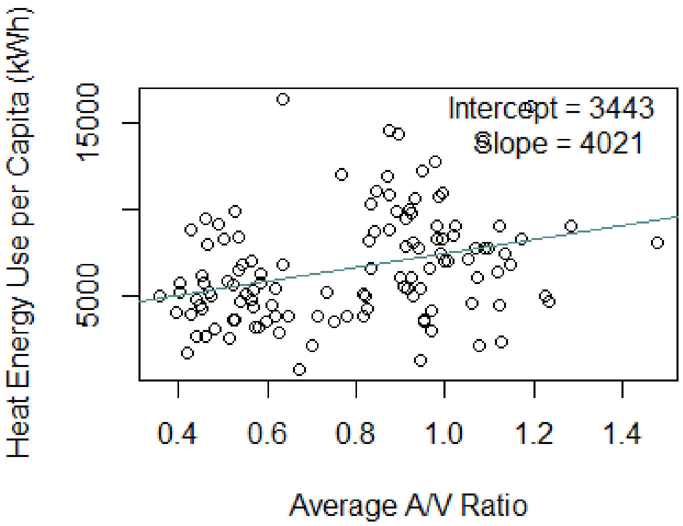


Figure 111: Scatterplot of Heat Energy Use per Capita (Y_{02}) and AV ratio (X_{14}) (Author, 2018)

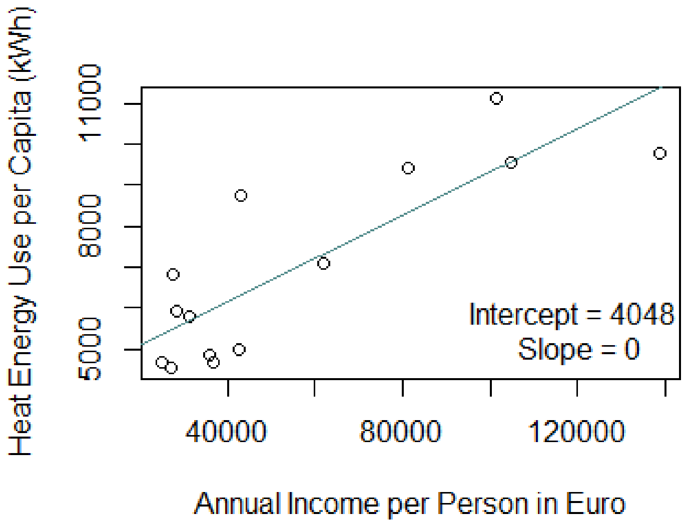


Figure 112: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Annual Income per Person (X_{15}) (Author, 2018)

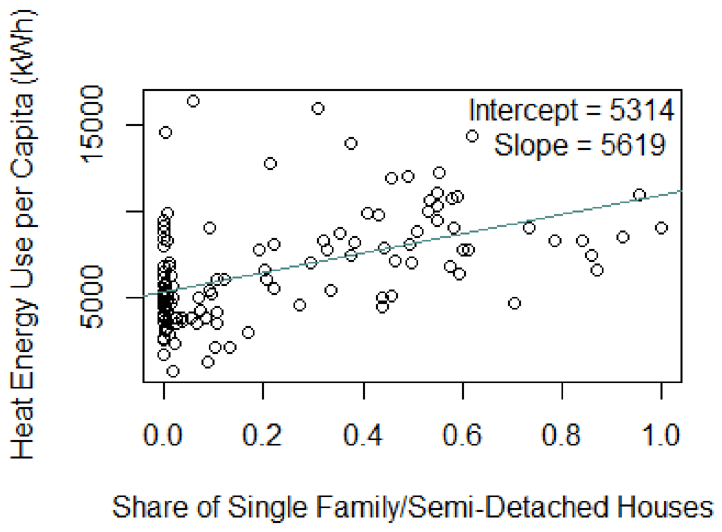


Figure 113: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Share of Single Family / Semi-Detached Houses (X_{typ1}) (Author, 2018)

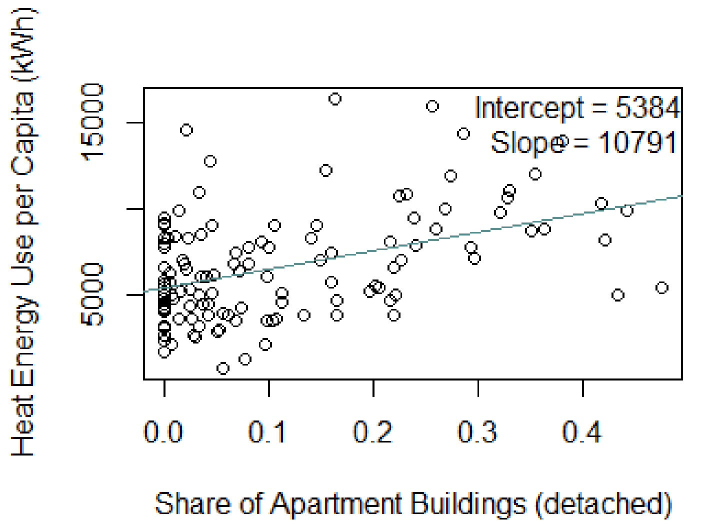


Figure 114: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Share of detached Apartment Buildings (X_{typ3}) (Author, 2018)

The contradicting tendency of the independent variable X01 was discussed in section 5.3.1 already. The positive correlation of all other variables however is more plausible.

Regarding the level of Statistical Areas, the scatterplots of all variables show only weak tendencies. The observations are located very loosely around the fitting line. Generally speaking, smaller building units (X_{typ1} and X_{typ3}) with a higher AV ratio (X_{14}) indicate higher levels of heat energy use. Large GFA per inhabitant (X_{07}) and age (X_{09}) also roughly indicate an increased heat energy use.

A difference can be seen again at the level of districs. For living area and income (X_{07b} and X_{15}) the observation points are located much more clearly along the fitting line. This explains why the coefficient of determination was so much higher for these two.

Second, the scatterplots of models with negative correlations are shown.

Figure 115: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Inhabitants per Hectare (X_{02}) (Author, 2018)

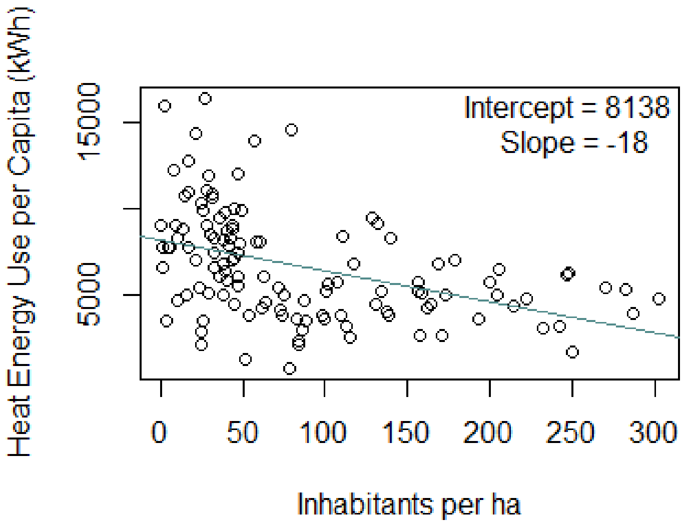


Figure 117: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Single Person Households (X_{03}) (Author, 2018)

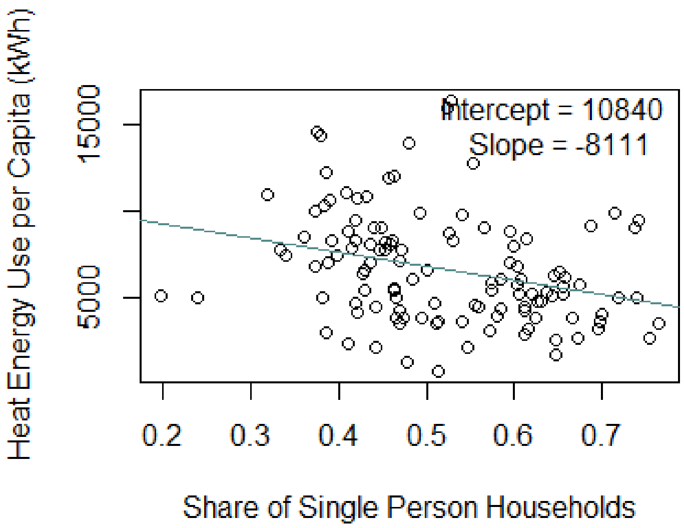
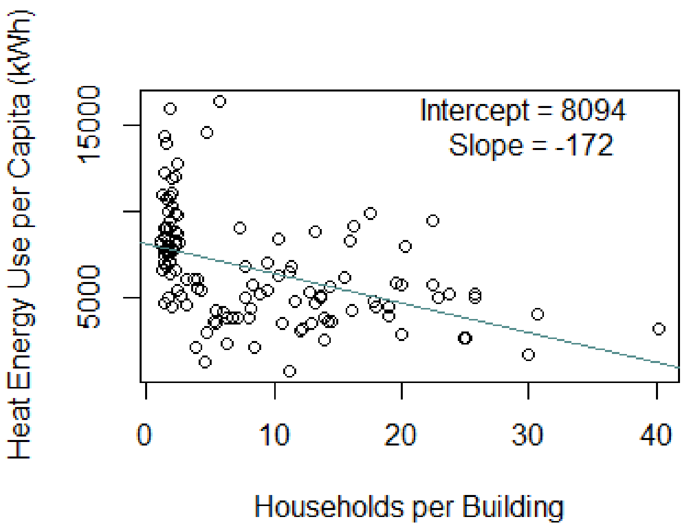


Figure 116: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Households per Building (X_{04}) (Author, 2018)



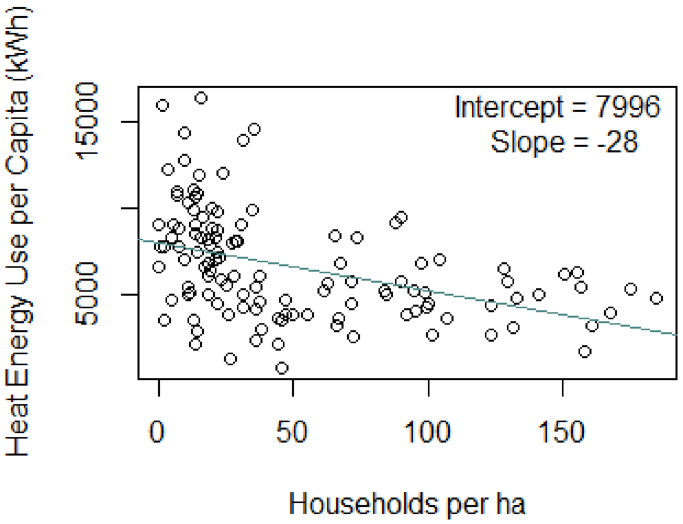


Figure 118: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Households per Hectare (X_{0r}) (Author, 2018)

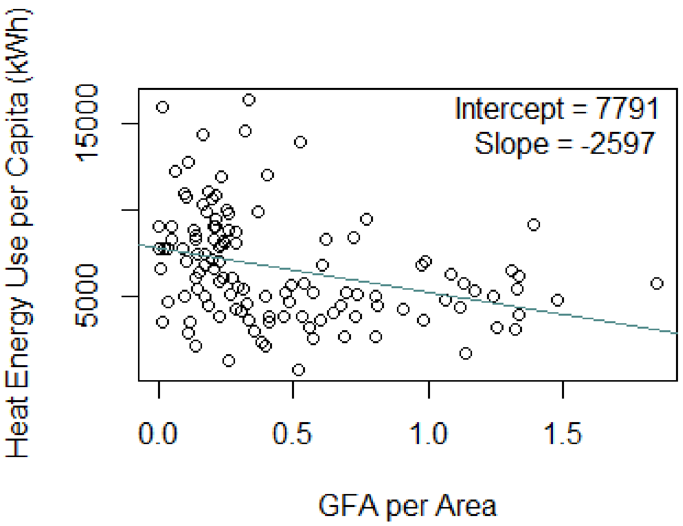


Figure 120: Scatterplot of Heat Energy Use per Capita (Y_{02}) and GFA per Area (X_{06}) (Author, 2018)

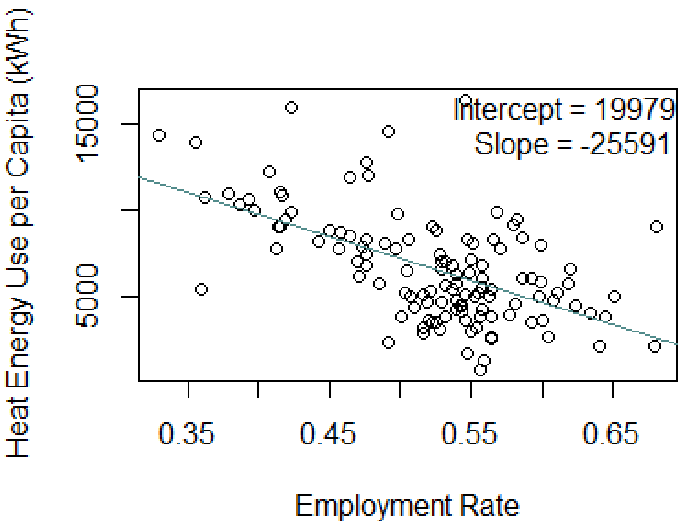


Figure 119: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Employment Rate (X_{10}) (Author, 2018)

Figure 121: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Unemployment Rate (X_{11}) (Author, 2018)

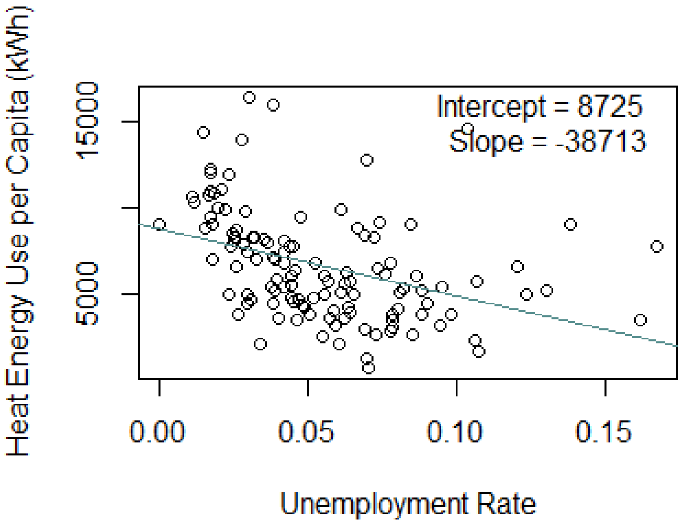


Figure 122: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Social Housing (X_{12}) (Author, 2018)

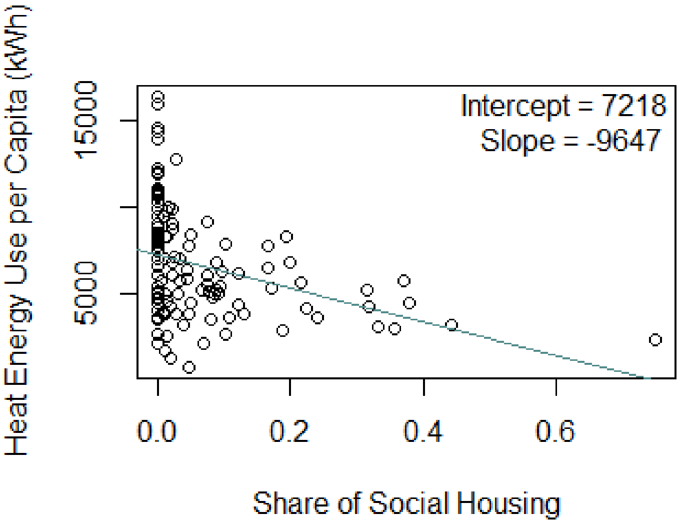
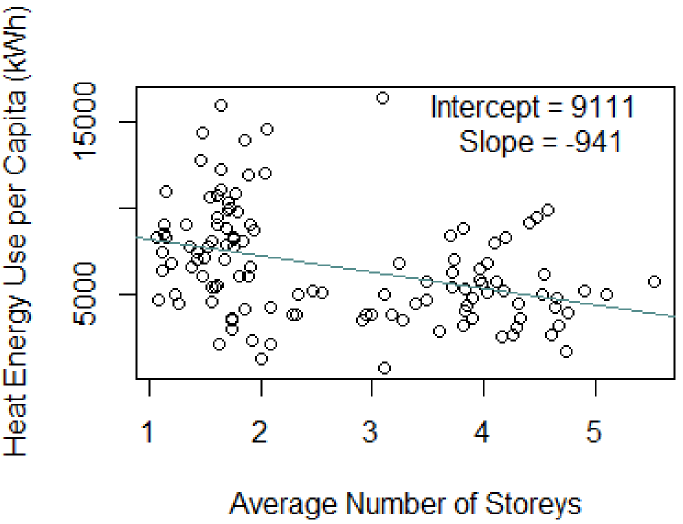


Figure 123: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Number of Storeys (X_{13}) (Author, 2018)



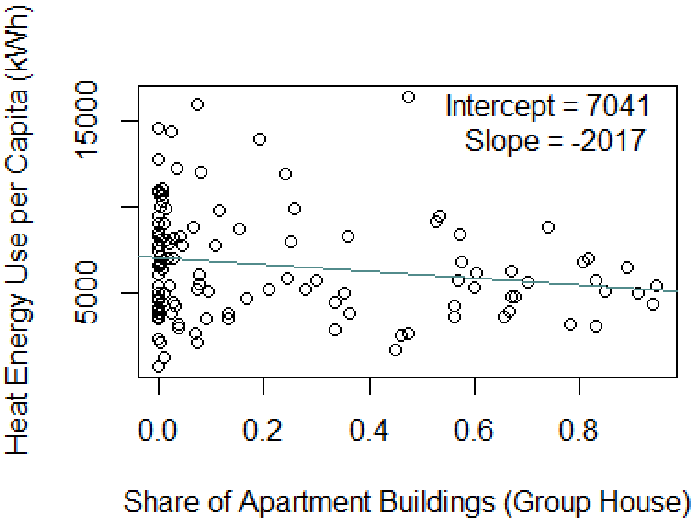


Figure 124: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Apartment Buildings in Groups (X_{typ4}) (Author, 2018)

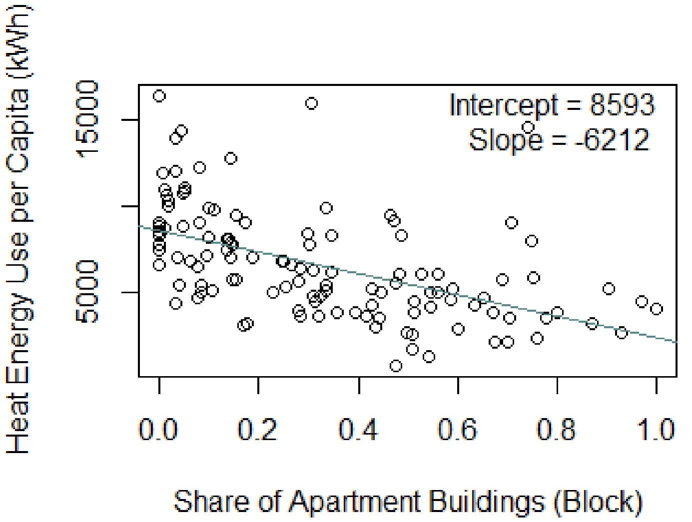


Figure 125: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Apartment Buildings in Blocks (X_{typ5}) (Author, 2018)

The scatterplots of variables correlating negatively with heat energy use show just like before why correlations are not stronger. Even when tendencies can be seen, there are many abnormalities.

Generally, compact buildings show lower levels of heat energy use. This is why X_{04} (households per building), X_{13} (number of storeys) and X_{typ4} and X_{typ5} (apartment buildings in groups and blocks) correlate negatively with Y_{02}, while X_{14} (AV ratio) correlates positively. High-rise buildings (X_{typ6}) do not show significant correlations, presumably because in most areas the share is rather low.

Overall, density also seems to indicate lower levels of heat energy use. This refers to inhabitants and households per hectare (X_{02} and X_{05}).

5.3.3 Multiple Linear Regression Analysis

In the multiple linear regression analysis significant regressors from the simple linear regression analysis are combined to optimize the model. Since regressors of building age did not correlate significantly with heat energy use in the simple linear regression analysis, none of them is kept. Out of the remaining variables only the ones which do not correlate with each other (cf. Table 11, Table 12 and Table 13) are included, just like it was done in section 5.2.3. This leaves the multiple linear regression model for Y02 with regressors as shown in Table 24.

The model can explain over half of heat energy use ($r^2 \geq 50$ %). The significance of the model itself is very high, but not of all the regressors. Consequently, a reduced model is developed.

X	Key point	Slope	Significance p	
Intercept = 15660; R^2 = 51.59 %			0.000	very high
X_{01}	inhab/hh	-362.7	0.775	no
X_{02}	inhab/ha	-11.1	0.019	moderate
X_{04}	hh/building	-9.3	0.826	no
X_{07}	GFA/inhab	57.2	0.000	very high
X_{09}	≥65 yrs	-3759.4	0.163	no
X_{10}	employm.	-16554.1	0.000	very high
X_{11}	unemploym.	-3734.0	0.649	no
X_{12}	social h.	-4993.5	0.030	moderate
X_{typ1}	EFH/DHH	-133.6	0.924	no
X_{typ3}	MFH single	-1058.0	0.628	no
X_{typ5}	MFH block	-1668.7	0.209	no

Table 24: Results of the Multiple Linear Regression Analysis for Y_{02} and all significant regresors from X_{01}-Xt_{yp6}

X_{01} still correlates negatively with heat energy use, but does not show any significance in the model. Along with all other non-significant variables, it is excluded from the reduced model. When again only the significant variables are chosen, r^2 and the p-value can be slightly improved. The only regressor left indicating high heat energy use is GFA per inhabitant (X_{07}). The others concern density of inhabitants (X_{02}), employment (X_{10}) and social housing (X_{12}). All three indicate low heat energy consumption, since they correlate negatively with Y_{02} (cf. Table 25). The model explains more than half of heat energy use.

The slopes define the relation. With every additional square metre of GFA per person, one uses 56 additional kWh heat energy. By contrast, every inhabitant per hectare indicates 8 kWh, every percent of employment rate 185 kWh and every percent of social housing 61 kWh less heat energy use.

X	Key point	Slope	Significance p	
Intercept = 14160; R^2 = 52.41 %			0.000	very high
X_{02}	inhab/ha	-7.6	0.009	moderate
X_{07}	GFA/inhab	55.6	0.000	very high
X_{10}	employm.	-18496.6	0.000	very high
X_{12}	social h.	-6112.2	0.001	moderate

Table 25: Results of the reduced Multiple Linear Regression Analysis for Y_{02} and X_{02}, X_{07}, X_{10} and X_{12}

Again, regressors of the same field are combined in multiple linear regression models. Employment and unemployment combined can explain with a very high significance heat energy use by 35 %. Just like before, both variables indicate a decrease of heat energy use.

X	Key point	Slope	Significance p	
Intercept: 19406; R^2: 35.89 %			0.000	very high
X_{10}	employm.	-22203	0.000	very high
X_{11}	unemploym.	-21864	0.005	high

Table 26: Results of the Multiple Linear Regression Analysis for Y_{02} and X_{10}-X_{11}

In the simple regression analysis none of the variables of building age showed significant correlations with electricity consumption. They are therefore not looked at in a separate multiple linear regression model.

The model including all significant regressors of building types shows a very high significance. However, there is no or only very little significance in every single variable. The model is therefore not suitable to explain heat energy use.

X	Key point	Slope	Significance p	
Intercept: 7312; R^2: 33.96 %			0.000	very high
X_{typ1}	EFH/DHH	1719	0.336	no
X_{typ3}	MFH single	4540	0.068	no
X_{typ4}	MFH group	-966	0.523	no

X	Key point	Slope	Significance p	
X_{typ5}	MFH block	-4394	0.014	moderate

Table 27: Results of the Multiple Linear Regression Analysis for Y_{02} and X_{typ1}, X_{typ3}, X_{typ4} and Xtyp5

5.3.4 Evaluation of Statistical Analyses

Correlations do not prove causality. A high heat energy demand is directly influenced by other parameters than the tested ones. Regarding hot water the possible parameters are a long time of use, as well as inefficient and luxurious equipment. It is assumed here that the need for hot water is approximately the same for every person. Parameters for space heating are also a long time of use, inefficient technical equipment and insulation, but additionally a large volume. Furthermore, the need for warmer temperatures can vary depending on thermal sensitivity of a person. Last, heat energy is also influenced by behaviour. When a room is heated, even though it is not used, or when a window stays open while the heating is turned on, heat energy use increases. Since these direct influences cannot be quantified, correlations with other variables are important. Their effects are discussed to understand connections.

Patterns in correlations with heat energy use are similar to those of electricity use. Building age does not have any influence on heat energy use, though many studies with Hamburg's climate plan among them assume a connection to exist (cf. section 3.3.6). Regarding the borough Altona, the existence of such a connection between building age and heat energy use at the level of Statistical Areas has to be denied. This complies with observations made by Manuel Gottschick, who states that retrofitting is much more influential (2018). Unfortunately, there is no registry of performed renovations, which is why the effect of retrofitting cannot be calculated at any level higher than the individual building level.

Just as it was the case for electricity use, single family houses and detached apartment buildings both indicate higher heat energy uses, while apartment blocks indicate lower energy uses. Heat energy use was low in areas, where buildings comprised a larger number of households. Indicators of compactness are more significant for heat energy use than for electricity use. Compact buildings can be quantified by the number of storeys and the A/V ratio. The more compact a building, the less heat energy is used. This can be explained by the reduction of heat loss (cf. section 3.3.6).

The conflicting result of the number of inhabitants per household has been discussed in section 5.2.4 and will therefore not be discussed here again. It is made clear again, that without further explanation the number of inhabitants per household and the share of single person households should not be used as indicator for energy use.

The other parameters of density have a significant impact on energy use. In areas with many inhabitants and households per hectare heat energy use tends to be low. Opposed to density parameters, a large GFA per inhabitant indicates high heat energy use. It is one of the strongest indicators at the level of Statistical Areas. At the district level, living area per person can even explain 66 % of heat energy use and is therefore an extremely good indicator. The reason behind it is clear: A large living area implies a large space to be heated. It is therefore only logical that the correlation is very strong.

A relation with the age of inhabitants can be proven for elderly people. When the share of households with people above 65 years is high, heat energy is high as well. This observation can either be ascribed to longer times of use or to higher heating requirements, which is also suggested by Jan Gerbitz (cf. Appendix P). A correlation with the share of households with children could not be proven. However, it could be interesting to phrase the definition of children more narrowly. Possibly, results are different when only households with infants are included instead of households with people under 18 years.

Just like before, employment and unemployment both are good indicators for heat energy use. This can again on the one hand be explained by the third group of people, who are neither employed nor unemployed, but have high incomes and use a lot of heat energy. It is therefore likely, that both variables basically describe the share of people with lower income. In areas, where the share of employed and unemployed people is high, smaller amounts of heat energy are used per capita. On the other hand employed people might be home less often and therefore need less heat energy, while unemployed people might try to save energy costs. For whichever reason, both indicators combined in a model can explain 35 % of heat energy use.

Similarly, it was shown in section 5.1.3 that in areas with high income, the share of social housing was low. Comparing heat energy use to electricity use, social housing plays a slightly larger role. Areas with a large share of social housing tend to use less heat energy. Multicollinearity could not prove a strong correlation with living area per person or other building or density related characteristics. Weak correlations possibly still exist, but the clearest connection can be drawn to income.

Income is the best indicator for heat energy use. It alone can explain 70 % of heat energy use, but could only be analysed at the level of districts. As described in section 5.2.4, income is the source for many other parameters. When income is high, so is the living area and consequently the air volume, which needs to be heated up. Large apartments are rather to be found in certain building types and less dense areas. The A/V ratio therefore tends to be less efficient. A large share of significant variables are in a way influenced by income. Unfortunately the lack of data on retrofitting does not allow an assessment on the connection between income and investment in renovation measures.

The model, which describes heat energy use at the level of Statistical Areas best, is the one including inhabitants per hectare, GFA per inhabitant, employment rate and social housing. These are likely to be all influenced and correlating with income. If data on income was available at the level of Statistical Areas, it alone could probably represent a much better model.

To sum up, similarly to the analysis of electricity use, heat energy use shows correlations with several variables. With regards to the structure of buildings, certain building types and compactness correlate significantly with heat energy use. Concerning the inhabitants, households with elderly people, the rates of both employment and unemployment, as well as income can serve as indicators for heat energy use. Urbanization, meaning density and living area per person, also showed significant correlations. In a model with four variables combined (explained above), over 50 % of heat energy use can be explained.

5.4 Connection between Consumption of Electricity and Heat Energy

In previous chapters electricity and heat energy use were analysed separately. But what is the relation between both of them? It has been shown that the indicators for both consumptions are mostly similar. Does this mean that electricity (Y_{01}) and heat energy use (Y_{02}) correlate with one another? Is heat energy consumption high when electricity consumption is high and the other way round?

At the level of Statistical Areas, Y_{01} and Y_{02} correlate moderately positively ($r = 0.50$) with a very high significance ($p = 0.000$). They can explain each other by 25 % ($r^2 = 24.96$ %). At the district level electricity and heat energy use correlate strongly with $r = 0.818$ and a very high significance ($p = 0.000$). r^2 is 66.99 %.

The simple linear regression analysis of the sum of electricity and heat energy consumption ($Y_{01} + Y_{02}$) at the level of Statistical Areas with all independent variables X shows very similar correlations and values of significance to the separate models (cf. Appendix N). However, measures for energy saving are very different for electricity and heat energy. In consultations, both consumption data is therefore looked at separately and measures are implemented independent from one another. The connection between Y_{01} and Y_{02} helps to know that when a household shows high consumption of one thing, it is worth looking at the consumption of the other, but they will always be treated separately. The analysis of $Y_{01} + Y_{02}$ will therefore not be looked at in more detail.

5.5 Summary on Statistical Analyses

First of all, it should be noted that the generation of data and aggregation to Statistical Areas involves several uncertainties. This can weaken existing correlations. The task therefore was less to prove existing correlations, but to find the correlations, which can be tracked with the available data. When correlations between energy use and chosen parameters exist despite unavoidable uncertainties, institutes and authorities can use these parameters in the future to understand energy use.

Income and living area per person are the best indicators for energy use per person.

Electricity and heat energy use have shown very similar indicators. They are therefore summarized in the following. Even though indicators are comparable, electricity and heat energy consumption are not completely congruent (cf. section 5.4). A high electricity use can indicate a high heat energy use, but not always. The indicators can easily be summarized, but in application on site the two consumption types should always be analysed separately.

In the beginning it was shown, how closely income and living area per person are related to each other. These two variables have an immense influence on electricity and heat energy use. A large living area per person is very likely to lead to more electric devices and certainly requires a larger air volume to be heated up. It can also be assumed that people with higher incomes tend to have more luxurious equipment such as a sauna or a pool, which needs additional energy. Large apartments automatically lead to less density and are more likely to be found in certain building types like single family houses. These buildings are less compact and therefore feature higher heat losses. All these aspects might not have been proven in Altona yet, but were clear to interviewed planners (cf. Appendix O, Appendix P, Appendix Q and Gottschick, 2018). Since data on income and living area is only available at the level of districts, they cannot be used to predict energy use in a more detailed way.

The task was to find variables, which correlate significantly at the level of Statistical Areas. Several factors were studied separately. Some variables correlate strongly with one another and therefore have to be kept in separate models. The goal is to find the ones describing energy consumption best individually and in a combined model.

Building age and people per household are not useful indicators for energy use per person.

A number of variables are not suitable to explain energy use. None of the variables on building age had any significant correlation with energy use. The level of retrofitting would probably be a far better indicator, but appropriate data is not collected. The number of inhabitants sharing a household and the share of single person households showed correlations to a certain extent, but in an implausible way. According to the data, when fewer people share a household, they use less energy per person. This contradicts existing studies and common sense. A possible explanation is that people living alone are home less often than people who share the apartment with family members and flatmates. The shortened utilization time would then overlay the negative effect of a small number of people per household on energy use per person. Another conceivable reason is less luxurious equipment in urban areas, since incomes were rather low in urban areas. However, the correlation of income and indicators of urbanization were not strong, so this hypothesis cannot be proven here. Both suppositions are speculative and need proof to be used as reasoning. As long as further data on utilization time does not exist, the variables of inhabitants per household and single person households should be treated with caution and not be used as indicators for energy use.

Employment and unemployment rate are the best indicators for energy use at the level of Statistical Areas.

Very good indicators for energy use are both employment and unemployment rate. The first one comprises all insurable employments in people between 15 and 65 years, and the second one all unemployment benefit claimants in the same age group. Both indicate low energy uses, meaning that the third group indicates high energy uses. There are two possible explanations for the correlation. The first possibility is the fact that the group of people between 15 and 65 years, who is neither insurable employed nor unemployment benefit claimants, has higher incomes. The two variables are therefore probably good indicators for energy use, just because they describe income levels. The second possibility refers to a shorter time of use for employed people and a more cost and energy efficient behaviour of unemployed people. However, none of the assumptions can be proven in this paper. At the level of Statistical Areas the two variables combined can explain 40 % of electricity and 35 % of heat energy use. It remains unexplained if this phenomenon is only true for the borough Altona or if it is also true in other places.

GFA per inhabitant and the share of households with elderly people both indicate high energy use.

When choosing only one indicator at the level of Statistical Areas, GFA per inhabitant is the most meaningful. Contentwise, it is closely related to living area per inhabitant, which was only available at the level of districts. However, it is only an estimation based on information provided by ALKIS and therefore not as exact. Despite the uncertainties, correlations can still be seen for both energy uses. 20 % of electricity and 25 % of heat energy can be explained by this variable.

The share of households with elderly people also indicates higher energy uses. It can be assumed that elderly people are home more often and therefore have longer times of use. But also their electric equipment could be older and less efficient and their thermal sensitivity might require higher indoor temperatures.

Dense areas and compact buildings generally indicate low levels of energy use.

An overall trend to be seen is that in dense areas less energy is used. Regarding heat energy, the compactness of a building is additionally of importance. In large, compact buildings, less heat gets lost and consequently less heat energy is needed. In dense areas the reason for energy reduction is not as clear however. Compactness of a building expressed by the A/V ratio is closely related to the density of households per building, which also indicates low heat energy use. However, it is not clear, why density should reduce electricity use per person. A conceivable possibility for people in dense areas using less energy is again the time of use. In dense areas a wider range of activities outside people's homes are offered. Inhabitants could therefore possibly be home less often, which would then lead to less energy use. The same assumption was made for people living by themselves in a household. Since single person households are to be found mostly in urban areas, both assumptions would fit together.

Regarding structural characteristics of residential buildings, some building types can indicate high or low levels of energy use. Single family or semi-detached houses as well as detached apartment buildings indicate high energy use, while apartment buildings arranged in blocks indicate low energy use. Social housing indicates a lower level of energy use as well. Despite the fact, that the test of multicollinearity did not show strong results, these characteristics are connected to density and income in a way.

It is not possible to combine all variables in one meaningful model to describe energy use. This shows that even if separate variables lead to significant results, they cannot be joined to create an even more significant model. Possible reasons are hidden multicollinearities and too high inaccuracies. Multiple regression models can vary depending on data availability, but only comprise a small selection of the given variables. As explained before, the combination of employment and unemployment rate alone leads to very good results already. When adding GFA per inhabitant, the results are improved further. The best results of a model for heat energy are achieved when inhabitants per hectare and the share of social housing are included. The best multiple linear regression model for electricity included building age group 2, which is not plausible. The main finding is that it is advisable to certainly include employment and unemployment rate, as well as GFA per inhabitant in models of energy use.

All in all, the most important indicators of energy use are income and living area. Since these are not available for Statistical Areas, other variables can be used. These concern building type, density and compactness, elderly inhabitants and as strongest indicators employment and unemployment rate and GFA per inhabitant. Consequently, structural characteristics as well as characteristics of inhabitants can both serve as indicators for energy use. Nevertheless, energy use is influenced by such a large number of factors, that even in the multiple regression models the coefficient of determination rarely exceeds 50 %.

Energy use is influenced by such a large number of factors, that even when the studied ones are combined in a multiple regression model, only around 50 % oft he energy use can be explained.

6 Evaluation

Previously, the importance of operational energy savings in the residential building sector was shown. In the study of chapter 5 correlations of energy use in Altona with several variables characterising the urban setting, inhabitants and residential buildings were calculated. This chapter will now draw conclusions for the borough and define recommendations. Also, the methodology for determing energy use and other indicators at the level of Statistical Areas and calculating correlations will be evaluated.

6.1 Recommendation for Action

In order to reduce GHG emissions coming from residential buildings in Altona, there are two strategies, which were detailed in section 3.5. The first one addresses energy efficiency. It targets the reduction of energy consumption, which automatically reduces the amount of emitted GHG. Here, existing interdependencies with framework conditions are of importance. The second strategy focuses on a reduction of GHG emissions per energy unit. When sources and technologies are changed, fewer GHG are emitted, even if the amount of consumed energy is constant.

The following sections recommend strategies from the perspective of the regional administration. Based on previous analyses and interviews conducted with different experts, starting points and first ideas of measures are developed. However, the recommendations do not indicate detailed instructions or guidelines. These need to be developed in a subsequent step. All strategies discussed refer to the level of Statistical Areas. They do not represent advices for the individual building level. Also, they mainly refer to the existing building stock, since it is more challenging to achieve reductions in energy use and emissions in the building stock than in new buildings.

6.1.1 Boundary Conditions

Energy use and GHG emissions in residential buildings in Altona are currently much higher than anticipated by climate targets (cf. section 4.7). Efforts need to intensify to reduce energy use and GHG emissions. Manuel Gottschick from OCF Consulting in Hamburg explains that the simplicity and frugality of required effort for savings are even more important than emissions themselves (2018). In comparison with other sectors such as food, mobility and tourism reduction measures are much less radical in the sector of residential buildings. Measures are easier to be carried out, less expensive and do not have a drastic impact on lifestyle (ibid.). These insights enhance the need for action in the residential building sector.

The analysis in chapter 4 has shown that Altona is a diverse borough. Areas located close or within the city centre show high densities and small GFA per inhabitant, but a large share of single person households at the same time. Also, the share of children and teenagers as well as elderly people is rather small in these urban areas. Buildings here are mostly multi-family houses arranged in groups, while single family and terraced houses tend to be located in the more rural areas in the west. Regarding income and employment, a difference can be seen between the northern and the southern half of the borough. The northern half shows high rates of employment and unemployment, while the southern half has a high share of neither employed nor unemployed people with high incomes. The geographical distribution of building age groups is rather mixed and cannot explicitly be assigned to a certain area. The pattern of energy consumption per inhabitant in contrast was very clear. Inhabitants living in the south of Altona, close to the river Elbe, consume up to twice as much energy as inhabitants living in other areas, resulting in much higher CO_2 emissions.

The great diversity inhibits the application of generalized measures. Instead, it can be useful to take a closer look at existing connections between boundary conditions and energy consumption. These were analysed in chapter 5. With this newly gained understanding of the composition of energy use, measures can be assessed in a better way. Connections can show need for action, but also limitations of saving potentials due to boundary conditions.

The following recommendation focus on areas, where energy use and emissions are high and the aim is to reduce these. Before implementation however, the potential of behaviour change needs to be considered as well. As Manuel Gottschick explains, measures are most effective, when a willingness for change exists (2018). This aspect will be addressed in the following sections.

6.1.2 Energy Efficiency

Universal influencing factors on final energy use based on existing studies were shown in section 3.3.6. Correlations of available data describing the urban setting, inhabitants and residential buildings in Altona with energy use were analysed in detail in chapter 5. These have brought several findings, which can be processed in energy saving measures.

Living Area per Person

The analyses have shown that the greatest impact on energy use in Altona is living area per inhabitant. Its importance rises even further, when the trend of increasing living area per person is taken into account. If living area per person was reduced, energy use per person in private households would most certainly decrease as well. Besides energy efficiency, growing cities like Hamburg have a general interest to use residential space more efficiently. What options are there to limit living area per person?

Ways to decrease living area per person need to be found.

Regarding new buildings, urban planners and policy makers should encourage certain building types, which facilitate smaller living areas per person. This implies a strengthening of large apartment buildings and the omission of new single family houses. However, influencing measures on living area per person in the existing building stock are more difficult.

A regulatory limitation of residential space per inhabitant is carried out in social housing, where residents are entitled to only a certain size of living area. The share of social housing and living area per person therefore correlate negatively. Energy use was consequently lower in areas with a higher share of social housing. An expansion of such a regulation towards the free housing market is discussed in Switzerland. However, it was shown that drastic regulations would counter other needs (Gmünder et al., 2016, p. vii).

Instead, the researchers propose less drastic measures, which are less effective but implementable. The first is called the density bonus. It allows developers, who create apartments with small living areas per person to develop a larger building (Gmünder et al., 2016, p. 53). The second option refers to subsidised housing only. The researchers propose to introduce limits of square metres and rooms per person, just like it is implemented in Hamburg already. For example, in a subsidised apartment for two people in Hamburg, living area cannot exceed 60 m² (IFB, 2016a, p. 25; IFB, 2016b, p. 21). The last proposal refers to inhabitants in around 10 % of households, who felt their living area was too big. The subjective perception of having too much living space did not correlate with income, but with the share of elderly people and couples without children (Delbiaggio & Wanzenried, 2016, p. 49). The last proposal concerns the support of these people to move to a smaller apartment (Gmünder et al., 2016, p. viii). The support can be complemented by an apartment trade platform (Delbiaggio, Wanzenried, 2016, p. 50). Since the connection between elderly people and large living areas per person was proven in Germany as well (such as Pätzold, 2018, p. 8), in several cities such as Düsseldorf and Berlin home exchange programs have tentatively pushed forward to enable downsizing after family members have moved out or passed away. So far, they have not been very successful (Der Tagesspiegel, 2017; WDR, 2018).

Several other barriers have prevented successful trade programs so far. An additional necessity is the existence of a willingness for down-sizing. The analysis has shown for Altona that living area per person correlates strongly with income. This could mean that the size of an apartment is a question of affordability, which would imply that a large apartment is generally desirable. More knowledge is needed to assess the will of inhabitants in Altona to move to smaller apartments. If such willingness existed, it would be highly advisable to support efforts of down-sizing.

Retrofits

Building age did not show any statistically significant correlation with energy use. A possible explanation refers to implemented retrofits, which blur the effects of different energy standards of different age groups. Whichever reason lies behind the observation, planners and policy makers should therefore be discouraged from focusing on buildings of a certain age group. This advice contradicts the information given in Hamburg's climate plan, which declares buildings erected before 1978 to have the largest share in heat energy use (Bürgerschaft der FHH, 2015, p. 29). This contradiction underlines the need for more local data to receive a better understanding of energy use.

A local inventory on retrofitting measures does not exist, which inhibits an estimation of the share of already realised renovations. Several studies have demonstrated the great influence of retrofitting measures on energy use. It was shown in section 3.2 that embodied emissions in materials used in renovations are amortised after only a short period. In new buildings with high energy standards the amount of embodied emissions relative to emissions during operation is much higher than in the existing building stock. Here, embodied emissions of different materials should be assessed in more detail (Appendix P). However, the focus of this paper is on existing buildings, which is why energy investments are assumed to pay off after only a few years.

Retrofits do not only refer to insulation, but also the adjustment of heating technology, including heating of hot water, which could reduce energy consumption by 10 % to 25 % (Gottschick, 2018). Also, smart thermostats helping to monitor and regulate heating and cooling loads can reduce energy demand by 15 % to 50 % (IEA, 2017, p. 45). Retrofits generally present a great potential to decrease energy use. Nationally, all residential buildings, with the exception of 15 % to 25 % which are exempt (e.g. historical-designated buildings), have to be renovated by 2050 (Bürger et al., 2016, p. 160-171). Similar retrofitting rates should be pursued in Altona. Nevertheless, such rates and areas with need for action can only be defined when being monitored. The introduction of a monitoring system, which records the energy standard of residential buildings, would thus be very useful.

Anticipated rates of retrofits require an appropriate monitoring system.

Potentials of energy saving through retrofits are highest in buildings with high heat energy use per living area metre (cf. Figure 85 in section 4.7). However, high energy use is not the only aspect to take into account when choosing areas for retrofits. When deciding on an area, ownership structure should be considered. Generally, retrofits are easier to perform when the investor benefits from energy savings and when the investor does not have to coordinate with other parties. The share of buildings inhabited by owners is only 24 % in Hamburg (BMWi, 2015, pp. 30, 31). Measures usually require changes to the façade or the heating system. When a building is owned by several parties, the community of owners has to decide collectively (BMWi, 2015, p. 30), which can complicate the procedure. Bezirksamt Altona has therefore decided to address areas with few owners and primarily approache housing cooperatives, who own a large number of residential buildings (cf. Appendix O).

Another approach can be to address areas where residential buildings only contain a small number of apartments and consequently a small number of owners. Single family and terraced houses for example are most likely owned by only one or two parties. The spatial distribution of these building types was shown in section 4.4.5. Since retrofits require a certain investment, it can be useful to overlay areas with a high share of single family and terraced houses with income (cf. Figure 53 in section 4.3.3). Areas meeting all three requirements regarding heat energy use per living area, building type and income, are mainly located in Blankenese, Nienstedten, Othmarschen and Groß Flottbek.

After having decided on areas to focus on, retrofitting measures need to be promoted and chosen. Several financial incentives are implemented already (BMWi, 2015, pp. 68-70). These need to be presented and promoted to owners. The development of standardized retrofitting measures (such as Dunkelberg & Weiß, 2016, pp. 42-46) would facilitate the execution of renovations further (Gottschick, 2018). If desired, the obtainment of certifications such as LEEED or the label E+C- (cf. Appendix R) can be supported as well. Some federal states have introduced green house number plates for households which comply with certain requirements.[I] This type of certification could also be promoted in Altona. An evaluation of measures to trigger a higher retrofitting rate was conducted in a study from 2015 by several institutes in Germany (Pehnt et al., 2015). Due to the limited scope, the results are not discussed in this paper, but should be evaluated and used for decision making in Altona.

Compact and dense Buildings

The analyses in chapter 5 have shown negative correlations of factors describing compactness and density with energy use. People use less energy when they live in areas with a high density of households and inhabitants per hectare, with large built-up space, and with compact buildings containing a high number of of storeys and households. These can be seen as characteristics of urbanization. A low number of inhabitants per household is also a characteristic of urban areas in Altona. None of these correlate strongly with living area or income per inhabitant, so density and compactness should really be seen as separate indicators.

[I] Such as Sachsen-Anhalt: https://grüne-nummer.de/ and Niedersachsen: https://www.klimaschutz-niedersachsen.de/umweltbildung-und-projekte/grune-hausnummer.html

Reasons for low heat energy use in compact buildings are obvious. Correlations of compactness with heat energy use were consequently stronger than with electricity use. From an energetic point of view, new buildings should be as compact as possible. Regarding the building stock, building extensions and the addition of another storey are possible ways of improving compactness and densification. Densification is envisaged by the department for urban planning in Bezirksamt Altona. According to Martina Nitzl, urban planner and contact person for the climate protection concept at Bezirksamt, the results confirm and reinforce the striving for more density (Appendix O). In terms of compactness, these measures can energetically be absolutely supported.

However, it is not quite clear why electricity use should be lower in dense, urban areas. The possible explanation of short periods of utilization was discussed before. It is possible that people in urban areas, who tend to live by themselves or with only few other people, are home less often and therefore use less energy. If this was true, it would automatically be the reason for low values in heat energy use in these areas. In this case, density itself does not reduce energy use, but the urban lifestyle. Assuming that people in urban areas really did spend more time outside their apartments, it would be useful to know if they spent the same amount of energy elsewhere, or if being home less often actually saved energy. If the absence at one's home has a negative impact on energy use in other places, this still has to be assessed. If the effect of utilization time on total energy use is not determined, an advisable strategy on development of urbanization cannot be given.

Possibly, urban lifestyles reduce energy use more than urban structures do.

Nevertheless, dense urban settings have other positive environmental impacts besides low energy use per person. These primarily concern mobility and land use patterns, as well as influences on living area per person. These aspects justify the strive for densification, while relations between energy use and density can only partly serve as supporting evidence.

Target Group

According to Ralf Niebergall, Vice President of the Federal Chamber of German Architects, planners and policy makers should not only focus on technological solutions, but should also consider behaviour and find solutions suitable for residents (cf. Appendix R). Structures of ownership and their relation to the effectiveness on retrofitting measures were discussed before. Regarding the characteristics of residents in relation to energy use per person, the analyses have shown that energy use is highest for elderly people, people with high incomes, and people sharing an apartment with several other people. These factors have a high influence on utilization time, living area and most likely also on thermal needs and equipment. They therefore indirectly affect energy use and cause the so-called performance gap, when actual consumption differs from technologically calculated energy demand.

Obviously, these factors cannot and should not be changed. As Ralf Niebergall points out, residents cannot be blamed for performance gaps (cf. Appendix R). The characteristics of inhabitants and their consequential behaviour represent an uninfluenceable framework. But knowing that these characteristics of inhabitants determine energy use can help defining a target group for further action. When energy use of these people is above average, this is where measures can be applied. People with high energy use cannot be requested to change their lifestyle, but energy efficiency measures in their homes can be justified much better. Firstly, measures have a greater potential for reduction when energy use is high, and secondly, energy uses above average can point out a certain liability to act.

The geographical distribution of this target group was shown before. Elderly people and people sharing a household with others tend to live outside the city centre. Among these areas, income is highest in the southern parts. To reach the target group, energy consulting can be promoted in these areas in the south of Altona, outside the city centre. During consulting appointments, high energy use can be verified at the individual level. This step is highly important to avoid preconception and stigmatization. It should be clear, that the analysis of chapter 5 only helps to narrow down the target group, but cannot indicate individual energy use. Energy consulting should therefore aim for the target group and by checking individual energy consumption decide on the effectiveness individually.

A first step for further action to be reached in energy consulting is awareness. Still, awareness alone should not be overestimated. According to Manuel Gottschick (2018), there is no causality between knowledge and behaviour. The big challenge is to find out the factors, which lead people to climate friendly behaviour. It is possible that a certain group of people are better reachable than others. In Manuel Gottschick’s experience, a good way to arouse interest and attention for new measures is to implement new climate concepts when an upheaval takes place anyways, for example when the central market place is transformed (2018). It can be advisable for planners in Altona to focus on areas where attention is drawn to changing processes already.

Possibly, it is more decisive to focus on personal advantages than on global climate issues.

Yves-Laurent Sapoval, Senior Advisor at the Ministry of Ecological and Inclusive Transition in France, and Brian Dean, Head of Energy Efficiency at IEA, state that when measures are implemented, the well-being of residents and personal comfort have to be at the centre of the discussion (cf. Appendix R). Personal advantages are likely to be more decisive for energy efficient action than awareness for the global issue of climate change. Once a target group is selected, it can be useful to focus more on these individual advantages than on global climate issues. Further evaluation is needed to prove this assumption.

Overall, there are characteristics of inhabitants which indicate higher energy use trends. It is mostly elderly people, people sharing their household with others, and people with higher incomes who consume more energy. This group of people tends to live in the south of Altona, outside the city centre. Consulting can verify individual energy use and assess effective measures. People are likely to be more influenceable when their attention is drawn to urban development processes already and when personal advantages are pointed out. The promotion and conduction of energy consultation in these areas, especially where projects of urban development take place already, can be recommended.

6.1.3 Carbon Intensity

In 1987 the the World Commission on Environment and Development stated in their report “Our Common Future”, that “energy efficiency can only buy time for the world to develop low-energy paths based on renewable sources, which should form the foundation of the global energy structure during the 21st Century” (UN, 1987). The statement emphasizes the importance of using less emission-intensive energy sources. Energy efficiency and reduced carbon intensity are both necessary, but the latter is absolutely indispensable as a long-term solution.

Different energy sources emit different amounts of GHG per generated energy. These were shown in section 3.4. A prioritization of energy sources can be made by favouring those with low emission factors. The use of energy sources with high emission factors in return should be minimized. Most factors do not include emissions of the upstream chain and auxiliary energy or emissions from GHG other than CO_2. However, since direct CO_2 emissions represent the largest share of emissions, the emission factors are still representative.

Electricity

Regarding the generation of electricity, renewable energy sources emit unequivocally less GHG than conventional energy sources. The anticipated increase of renewable energy sources in the energy mix is therefore crucial and should also be supported in Altona. Implementation potentials are limited in dense, urban areas, though not impossible. Photovoltaic panels can be installed on facades and roof tops, as long as they receive enough solar radiation. The installation of wind turbines or drills for geothermal power may be more difficult. In less urban areas of Altona, more space is available for renewable energy technologies. Detailed case studies could help evaluate the potential for different technologies in Altona’s suburban areas.

Case studies on potentials of renewable energy sources in Altona are needed.

When a power plant generates more electricity than the respective building can consume, it should be connected to the grid to supply other users as well. Since the generation of electricity with wind and solar energy is not constant, solutions of flexible energy use and storage are needed. These can refer to so-called smart markets and smart homes, which use electricity when surpluses occur. When using electricity, which would otherwise be lost, a change from other fuels to electricity can be supportive. For example, car engines and heating can be switched to electric power. Electrification is a keyword, which planners should keep in mind for future development. However, before planners in Altona focus on electrification, the emission factor of electricity needs to be reduced, meaning that more renewable energy sources have to be implemented.

When the installation of technologies using renewable energy sources is not possible, users can still influence the generation of electricity by entering into contract with certain suppliers. Deciding for a supplier who uses only renewable energy sources represents a very simple and doable step to take for people in private households. The great advantage is also the fact that the decision is up to every individual person. The decision for sources of electricity lies within the freedom to act of every single person. Policy makers should emphasize the importance of this very simple action of private people.

The call for more renewable energy sources in the electricity mix could be more meaningful if it was substantiated by knowledge about current electricity supply. Even though it would be possible to receive data on electricity suppliers, it is currently not possible to estimate the amount of so-called “green electricity”. As an initial approach, data on electricity suppliers could still be queried to attempt an assessment based on offered products of the suppliers, since some suppliers offer green electricity only. Alternatively, planners could conduct a survey to get a better picture on energy sources for electricity. However, this option requires a lot of effort and does not ensure representative participation. The data query on energy suppliers and the attempt to evaluate these is therefore recommended as preferred option.

District Heat

Altona’s entire city centre is connected to district heat owned and operated by Vattenfall. After a referendum in 2013, the city now negotiates with Vattenfall about the repurchase of the grid. A publicly owned grid would give authorities more decision-making powers over district heat and is therefore important for future developments. Currently, the emission factor of provided heat is 314 g CO_2/kWh. The environmental impact of its use is consequently worse than the use of gas and approximately as bad as the use of petroleum. Its carbon intensity can be traced back to the usage of coal in the cogeneration plant Wedel. According to Hamburg’s environmental senator Jens Kerstan, the plant is supposed to be switched off by 2022 and replaced by a waste incineration plant, industrial waste heat and a heat pump located south of the river Elbe (Meyer-Wellmann, 2017). This would reduce the emission factor of the district heat grid and make it a supportable energy source. Its new carbon intensity still needs to be assessed. Only when the amount of emission savings is known, recommendations regarding its competitiveness can be made. Until a decision is made, planners and policy makers should campaign for a quick replacement of coal with less emission-intensive energy sources.

The district heating grid of other operators show very diverse emission factors. The “Verbund Altona” operated by HanseWerk Natur has an emission factor nearly as high as that of the grid operated by Vattenfall, whereas the “Verbund Lyserstraße”, also operated by HanseWerk Natur, emits only a fourth of CO_2 per generated energy unit. This shows that an overall rating of district and local heat is not possible. District heat contains a great potential of low carbon intensity, but it depends highly on used energy sources, technology and heat losses during transmission. When grids are extended or newly implemented, it is recommended to define an anticipated emission factor. To make district heat competitive with gas as the most used energy source, its emission factor should certainly be below that of gas, which is 230 g CO_2/kWh. The implementation of new local grids in Altona can take place within existing initiatives such as KEBAP[I] as well as when the development of quarters is planned.

From a planner’s point of view, the great advantage of district heat is the fact that it is operated by a single company. To discuss a change of energy sources, only the operator and not all users need to be approached. Taking the perspective of inhabitants, it can be frustrating not to be able to choose between energy sources but to be bound to the district heat that the building is connected to. The shift of responsibility should be considered when identifying emissions caused by heating.

Other Sources for Heat Energy

Buildings, which are currently not connected to the grid of district heat, either use gas, petroleum, electricity or renewable energy sources. Similar to the suggested inventory of the energy standard of buildings, an inventory of used energy sources for heating would be a useful tool for planners. Only with a better data situation can the status quo as well as progress be estimated.

Regarding average values of the entire borough, the share of households using electricity for heating is very small. Electricity has the highest emission factor, but also the potential for a decrease. In the future it might be appealing and environmentally acceptable to

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[I] More information on current plans at
http://kulturenergiebunker.blogspot.com/p/energie.html

use electricity for heating. Some future scenarios for emission reduction in the residential building sector therefore show an increase in the use of electricity (cf. Bürger et al., 2016, p. 174). Currently, a recommendation for households in Altona using electricity to switch to a different energy source cannot be made. But certainly, the choice of electricity supplier is of great importance when using electricity for heat.

Petroleum is still used in 14 % of households in Altona. Its emission factor is very high, over 300 g CO_2/kWh, and does not show potential for reduction. Clearly, a shift from petroleum to other energy sources is highly advisable. Planners and policy makers should therefore approach owners of households, who use petroleum to generate heat. However, the localisation of these households creates difficulties. In its census, the Statistikamt Nord surveys energy sources used for heating, but data protection does not allow a transfer of individual data. Instead, chimney sweeps can be approached, since they have data on energy sources used in every household they serve. Certainly, privacy issues have to be clarified first. If households using petroleum for heating cannot be approached for whatever reasons, an obligation to shift from petroleum to other energy sources should be discussed. Whichever path is chosen, it is clear that the use of petroleum for heating has no prospects. Planners should push towards an early shift to other sources.

More than 40 % of households use gas as energy source for heating. As the comparison of emission factors has shown, among conventional energy sources and also in comparison with some district heating grids, gas is less carbon intense. A change should therefore only be performed when it leads to further reductions. Possible alternatives are district heating grids with low emission factors and renewable energy sources. In a long-term plan, the shift from gas to renewable energy sources is inevitable (cf. Bürger et al., 2016, p. 174).

On average, renewable energy sources used for the generation of heat emit the least amount of GHG. However, the installation of these technologies usually requires some sort of space, such as pipes for solar thermal energy on the roof top, pipes for environmental heat in the ground and pellets in the basement. To aid in informed decision-making, it could be useful to create an overview of requirements and benefits of every energy source for interested owners of residential buildings. Also, potentials in urban and suburban areas should be assessed to geographically determine households to be approached. Most likely the easiest way to integrate renewable energy sources is by installing a fireplace and burning wood. However, the amounts of emitted GHG through the combustion of wood should be communicated very clearly. Altona should take a stand on how these direct emissions of renewable energy sources should be evaluated. Different options were discussed in section 3.4.4.

The great difficulty with heating is the fact that the choice of technology and energy source lies in the responsibility of owners instead of users. The structure of ownership was discussed before with regards to retrofitting measures, resulting in the advice to approach residential buildings ideally owned by only one or few parties. As long as voluntary action is targeted, the same advice can be given here. Again, the best way to trigger voluntary action, is by offering energy consultations to interested people. The easiest way to reach all people however is by introducing regulations with obligations (cf. Gottschick, 2018). Even though it is the harshest option, it is the most effective one as well and should therefore always be considered and discussed with responsible authorities.

6.1.4 Climate Targets

Altona as a borough of the city of Hamburg is automatically involved in Hamburg's climate targets. These define reductions of total emissions, emissions per person and per living area. These targets are sufficient and do not need further addition. Moreover, as Jan Gerbitz, planner at Zebau, explains, many involved parties such as housing cooperatives are represented in several boroughs of Hamburg and would hardly be able to react to different requirements in different boroughs. Targets and standards should be the same in all areas of Hamburg (cf. Appendix P), so there is no need for Altona to define its own climate targets.

The Bezirksamt Altona commits to support Hamburg's targets (cf. Appendix O). Still, the question which needs to be answered is whether Altona should persue the fulfilment of these targets more actively. Instead of only supporting Hamburg, Altona could take on the same targets and aim to fulfil them individually. The clear formulation of targets and reference to the borough could evoke motivation (cf. section 2.3). Also, it would present a frame for measures and quantify the need for climate action. However, according to Manuel Gottschick, targets are usually only useful in a political environment when budgets are distributed. He doubts that the formulation of targets helps to reach private people (Gottschick, 2018).

Either way, setting clearly defined goals referring to emissions or energy use would require keeping track of progress. As Stephan Seiler, employee at the State Ministry for the Environment and Energy (BUE) states, variance analyses allowing a comparison of actual and anticipated values need to be possible. This requires good quality of data and constant surveys (cf. Appendix Q). A monitoring system will be introduced in Altona as part of the climate protection concept, but its framework is not clear yet (cf. Appendix O). Currently, through Hamburg's bottom-up accounting of the effects of single measures on emission savings can be shown. However, as Jan Gerbitz describes, the approach includes several uncertainties as well (cf. Appendix P). Also, it withholds an overview of total emissions and can therefore only be used for Hamburg's target of 2020. For future accounting, a system would be useful, which monitored total emissions and energy use. Only then would a comparison with Hamburg's targets for the years 2030 and 2050 be possible. An exemplary approach was shown in this paper.

Quantifying progress would increase responsibility. Determined numbers can serve as justification for measures on the one hand, and as obligation to act on the other hand. As Stephan Seiler states, measures would have to be designed according to the set goals (cf. Appendix Q). Additionally, such a new accounting method would enable Bezirksamt Altona to envision different pathways to achieve certain goals. For example, it could help to gain a better understanding about how the ambitious goal of reducing final energy use for heating to between 40 kWh/m^2 and 55 kWh/m^2 can be achieved. This understanding does not exist at the moment (cf. Appendix P). At the same time, non-compliance would be exposed. Also, a certain effort is needed to regularly update the data.

Mitigation targets are closely connected to monitoring. Currently, there is a large knowledge deficit regarding local monitoring of emissions (von Storch et al., 2017, p. 279). All advantages, disadvantages, threats and opportunities need to be evaluated by policy makers before deciding on the monitoring system. Overall, a monitoring system which enables the quantification of energy use and emissions would express the seriousness and commitment of Altona to achieve Hamburg's goals.

6.2 Assessment of Methodology

A quantitive evaluation of current energy use of residential buildings in the different parts of Altona had never been conducted before. Regarding influential facors on energy use, different studies suggest certain relations, but a more detailed estimation for Altona specifically had not been possible due to lack of data. The developed approach of this paper can therefore be seen as innovative. Such a new approach gives rise to several questions regarding its usefulness, possible conclusions drawn from the results and its applicability. The following sections aim to answer these questions with the help of interviewed experts.

6.2.1 Information Value

As explained before, a monitoring system of energy use and resulting emissions in the sector of private households currently does not exist. The way data on energy use was obtained, processed and geographically presented in this paper is an innovative approach. The information value is therefore immense for a start. According to Stephan Seiler, the largest gain is the possibility to assess the current situation geographically (cf. Appendix Q). To Martina Nitzl from Bezirksamt Alona it is of high value to see where residential buildings are in terms of energy targets and which areas have a good chance to achieve these (cf. Appendix O). Also, the obtained and illustrated data stands out, because it presents actual consumption data, whereas most studys only have access to estimated energy demand (Gottschick, 2018).

Coloured, graphical illustrations are useful means for communication (Gottschick, 2018) and can help to create awareness (cf. Appendix Q). Stephan Seiler points out that it is important to be clear about the message that is tried to be brought across, since not all information nourishes a constructive discussion (cf. Appendix Q). Regarding possible threats of such illustrations, the opinions among the experts differ. Jan Gerbitz points out the danger to stigmatise certain groups of people, for example when people in high-consuming areas feel assaulted (cf. Appendix P). Conversely, Stephan Seiler does not see a problem as long as data privacy is protected (cf. Appendix Q).

The choice of unit of the presented data highly depends on the target group. Planners for example need energy per base area, and policy makers units to compare with targets, such as energy use per living area. All experts agreed that for private people by contrast, specifications of energy use and emissions are most meaningful, when indicated per person (cf. Appendix O to Appendix Q; Gottschick, 2018). The use of data per person also has the advantage of including the effect of increasing living area per person. Data per living area would show constant improvements, but neglect the fact that total emissions increase (Gottschick, 2018).

Generally, such visualizations raise several questions. According to Martina Nitzl further information is needed when neighbouring Statistical Areas reach very different values of energy use (cf. Appendix O). Also, results of employment and unemployment rate were contradictory at first sight and would certainly need detailed explanations in order to ensure an accurate understanding. Overall, the background information should be clear, so that arising questions can be answered in an easily-understandable way (cf. Appendix O).

The greatest weakness of the developed illustrations certainly is the number of uncertainties, which were involved in the process. Even though the obtained data on energy use relies on accurate values, several assumptions were necessary in the process. Additionally, data on buildings obtained from ALKIS and Ecofys were not complete and therefore contained uncertainties. Before using the developed visualizations in public, one should be clear about the extent of these uncertainties and the general quality of data (cf. Appendix Q). Also, for a higher validity, more differentiated emission factors of electricity are needed (cf. Appendix O and Appendix P). As Martina Nitzl states, if data is not sufficiently accurate, a public discussion is better to be held qualitatively than quantitatively (cf. Appendix O). Further discussion on the quality and benefit of the presented data is needed before making a decision on its further use.

The obtained and processed data was then used to calculate correlations with energy use per person. These correlations are valuable for several parties. Authorities working on a pathway towards a certain reduction goal need to take into account influencing parameters. Planners and operators of heating grids have an interest in estimating energy use of certain districts to design the grid accordingly, and researchers calculating energy demands (such as for the Wärmekataster for Hamburg) need to know which parameters to include or exclude.

In the statistical analysis, since the same data as previously presented in maps was used, the same uncertainties are involved. In calculations of correlations, uncertainties are likely to blur existing relations. The results are therefore still meaningful and would probably be more significant with fewer uncertainties.

To all interviewed experts, the results of the statistical analysis were mainly expectable and not surprising. The fact that energy use is low in dense areas and high in areas with high incomes as well as in households with elderly people is well-known. This knowledge could be proven by the analysis. Still, there are two valuable aspects of gained knowledge. Firstly, at the level of Statistical Areas, energy use does not show any significant correlation with building age and secondly, in households with several inhabitants, energy use per person tends to be higher. This information does not comply with common knowledge, which is why the results should serve as impulse to reconsider current assumptions. Calculation approaches of energy demand are not available here, so variables included in the calculation are not known. But it can be assumed, that building age and the number of inhabitants per household are usually included in some way. If this is the case, the results of the statistical analysis questions existing approaches.

The statistical analyses have shown that only few variables can be combined in a model to describe energy use optimally. This information is valuable insofar as it indicates correlations to be meaningful indidividually, but not so much collectively. It is unlikely to find a model with several independent variables, which predicts energy use.

Though broad to a certain extent, the analysis has only limited explanatory power. The results certainly express relations existing in Altona in 2015, but further verification is needed to see whether the results can be transferred to other places and other years. The other boroughs in Hamburg show different characteristics. It would be interesting to see, if the same correlations existed there. Going further, it is uncertain, what results would be received in other states in Germany with structures even more different from Altona. Furthermore, some parameters such as living area per person and income change over time. It is not clear, if even within Altona the same results would be obtained for other years. All these questions need to be answered before applying the analysis to other years and other places.

6.2.2 Meaning for Mitigation Action

Regarding the geographic illustrations of energy use and resulting emissions, a consequential approach of mitigation action could be to address areas with high energy use and high emissions. However, as Manuel Gottschick says and as it was explained before, the question is not so much where energy use and emissions are highest, but where they can be reduced (2018). This question requires more information on other factors such as the inhabitants' attitudes, possibilities for behaviour change and already undertaken measures. This information is difficult to get, but it would be possible to collect information on existing initiatives and envisaged projects. These could be overlayed with data presented in this paper to draw further conclusions for mitigation potential.

Jan Gerbitz from Zebau notes that to planners of heating grids, it would be more useful to have images of heat energy use per base area. This visualization of heat density would be decisive for further feasibility investigations (cf. Appendix P). Since data on energy use per Statistical Area and the size of every area are both present, the available data could easily be used to create such an illustration, which would be able to help deciding on the implementation of new grids or the extension of existing ones.

First attempts of concluding recommendations for action were made in section 6.1. Generally, all interviewed experts found it difficult to jump to conclusions based on existing correlations. One reason is the open question of confounding variables, as Jan Gerbitz states. Several factors, such as building type and density could be influenced by another factor, such as living space, which again is determined by income (cf. Appendix P). Probably the main issue is the fact that existing correlations do not show immediate need for action. For instance, interdependencies between age or income and energy use cannot lead to the conclusion to lower the age or income of inhabitants. Instead, the results raise several questions. As Stephan Seiler suggests, these questions could concern the target group for public outreaches (cf. Appendix Q). Further, conclusions regarding structural characteristics and the general development of urban planning need to be drawn carefullly.

Regarding the level of detail, all experts agreed on its applicability. As Martina Nitzl says, the effort required to obtain data at the next lower level of building blocks or even the individual building level would be unreasonably high (cf. Appendix O). Stephan Seiler emphasises the preservation of data protection at the level of Statistical Areas as a great benefit (cf. Appendix Q). Still, the level is detailed enough to see geographical differences among the borough Altona. Stephan Seiler agrees with Manuel Gottschick, that people can identify with an area, which can increase awareness and willingness. First estimates can be made, which allow the initiation and organization of transformation processes based on this level of detail. The implementation itself however happens at a much lower level of quarters, neighborhoods and streets (Appendix P; Gottschick, 2018).

Generally, the processing of data with a Geographic Information System (abbreviated: GIS) contains a great potential for decision making. When certain boundary conditions for interventions such as energy density and building type are set, they can be overlayed in GIS. The program can then automatically select and display areas to which the conditions apply. This could be a great help for planners to decide where to go into further detail. Once an area is chosen, further surveys can be conducted, which indicate specific measures such as the determination of local grids. As explained by Jan Gerbitz, this process is currently mostly done manually (cf. Appendix P). It could be automated with the use of GIS. The fact that in this paper actual energy consumption in Statistical Areas was worked out, whereas planners usually have to fall back on estimated energy demand, represents additional potential.

6.2.3 Replicability

Applicability in the future is characterized by replicability. Required effort for the collection of used data differed considerably. The social indicators are published annually and therefore easily accessible. Since they are updated annually and continuously available, they can be used for the analyses of any year. Data on the use and location of buildings can be obtained through ALKIS, which is accessible through authorities such as Bezirksamt Altona and universities. ALKIS is updated yearly. The data needs to be modified and adjusted to defined requirements. This data management demands GIS knowledge, but can otherwise easily be replicated.

Data on building type and age is much more difficult to obtain. In this paper, the result from a study conducted by Ecofys was used. They were available through Bezirksamt Altona. However, the information was not complete and is not updated. For future analyses, alternative data would be needed. Otherwise the aspects of building type and age will have to be excluded.

The collection of energy data involved an immense effort, because privacy and the protection of individual data needed to be ensured. The process of receiving all consumption data has taken over a year, which is too much time for the analysis to be carried out again in the future. However, since now all contact persons and basic conditions are known to the parties involved, new data queries are likely to consume much less time. Also, in the future when Vattenfall's district heating grid has been repurchased, public ownership is likely to speed up the process. Consequently, the collection of energy data should in the future involve manageable efforts.

The illustration of data in coloured maps requires GIS knowledge, which is a skillset that is common to urban planners. For the calculation of correlations, skills to work with statistical programs are required. With the help of people with such skills, the analyses are replicable.

6.2.4 Comparison with Climate Protection Concept

As described before, the two engineering offices Zebau and Averdung currently develop a climate protection concept for the borough Altona. During their work, they also used energy use of residential buildings and worked out potentials. So where is the difference to the analyses of this paper?

Projektträger Jülich (abbreviated PtJ), the company who edits submitted grant applications for climate protection concepts, provides a framework for such plans. First of all, climate protection concepts have to include all sectors, such as land management, mobility, waste, waste water, industry and private households (PtJ, 2017, p. 3). This shows a main difference in the range of processed data. The residential building sector is only one of many sectors covered by Altona's climate protection concept. This has an impact on the depths of analyses, which will be explained later on.

Climate protection concepts constitute a strategic decision-making and planning tool. They are supposed to show technical and economical potentials for energy and GHG emission savings (PtJ, 2017, p. 3). Regarding the residential building sector in Altona, employees from Zebau and Averdung created a so-called heat map showing density of heat energy use per base area. According to Jan Gerbitz, the goal is to find areas with a high heat density, which are not connected to district heat yet, and to propose the installation of local heating grids with low emission factors there. A high energy density is needed to make these grids profitable. Initially, it is irrelevant if the high energy use is caused by a small number of people with a high energy demand per person, or many people with a low energy demand per person. The number of supplied people is more important at the phase of construction when costs per heat energy unit are determined (cf. Appendix P). Consequently, the illustration of energy use and emissions per person and per living area are less relevant. The climate protection concept therefore takes individual behaviour as fixed and proposes technological solutions to reduce emissions. This is a difference to the analysis in this paper. It by contrast puts the individual person in the spotlight and focuses on data per capita. The aim is to reach further understanding on the composition of energy use in residential buildings by relating residential and structural characteristics to energy use. This is done in a quantified, systematic way. The main result of the analyses is not a list of specific measures, but the obtainment of much deeper background information.

According to PtJ, specific targets are supposed to be based on national targets of emission reduction (PtJ, 2017, p. 3). When looking at the climate protection concept of the borough Bergedorf from 2016, reduction goals are not to be found. Instead, strategies on general emission reduction were developed (cf. Gottschick et al., 2016). A similar approach can be expected in Altona. This represents a large difference to the analysis in this paper, which quantifies energy use and emissions in order to compare them with mitigation targets. Details about the monitoring system to be introduced in Altona are not yet known (cf. Appendix O). Methodologies developed in this paper could be transferred and used as part of climate management in Altona. So far, based on current knowledge, it can be said that the climate protection concept rather stands for a qualitative approach, while the analysis of this paper represents a more quantitative approach.

6.3 Results and Research Questions

Having detailed the entire analysis, the research question in section 1.2 can now be addressed.

1. What is the impact of the residential building sector on the climate?

When indirect emissions are included, between 10 % and 20 % of all emissions originate in the residential building sector (cf. section 3.1). This share is true on all levels - worldwide, in the EU, in Germany and in Hamburg. Estimates highly depend on the accounting method, which is why quantifications can vary.

2. Which area within the residential building sector has the largest impact on the climate?

Regarding the phases during the lifespan of a building, emissions are highest during operation (cf. section 3.2). Emissions occurring during construction and demolition are not to be neglected, but in comparison with operational emissions, they are rather small. The importance of construction increases with a rising energy standard of buildings, which requires more materials during construction and less energy use during operation. However, when looking at an urban setting like Altona, most buildings are erected already, which is why the management of the building stock is of high importance.

The benefit of retrofits can be expressed in amortisation periods. Most installed devices were amortised after only a few years maximum. After this period, more emissions were saved than used in the course of construction.

Focusing on the operational period, energy is used for several applications (cf. section 3.4). In Germany, over half of all emissions of private households are caused by space heating. The second largest emitting application is hot water. Since electricity has a very high emission factor, the share of electric applications such as cooking, cooling, lighting, communication and entertainment represents a forth of all emissions, although the amount of energy used for these applications is rather low.

3. Which characteristics influence the energy use in residential buildings in Altona?

The regression analyses show correlations of parameters on urbanization, resident and residential buildings with energy use per person (cf. chapter 5). These show relations but should not be confused with causality. They represent indicators of high or low energy uses, but the actual influences still need to be discussed.

Correlations of variables with electricity use are very similar to correlations with heat energy use. The strongest correlations are achieved for the parameters of income and living area per inhabitant, even though these are only available at the level of districts. The variable of GFA per inhabitant is closely connected to living area per inhabitant and available at the lower level of Statistical Areas. It shows moderate correlations with electricity and heat energy use.

Regarding variables of urbanization, high rates in inhabitants and households per hectare, as well as households per building indicate low energy use. Among the variables describing inhabitants, high rates in households with elderly people and in employment as well as unemployment rate indicate high energy use. The last two variables combined represent areas of lower incomes and therefore indirectly describe income. Regarding residential buildings, high shares of single family houses and detached apartment buildings and low shares of apartment buildings arranged in blocks indicate high energy use. Additional variables show correlations with heat energy use only. These refer to social housing and the compactness of buildings. A high rate in social housing and number of stories as well as a low A/V ratio indicate low heat energy use. This means that energy tends to be low in dense, urban areas with compact buildings where only few elderly people live and where most inhabitants are either employed or unemployed.

The share of households with children and teenagers and all variables on building age do not show any significant correlation with energy use per person.

According to the regression analysis, a high number of people per household and a small share of single person households indicate high energy use per person. This observation contradicts common sense, but can be explained by shorter utilization times of people living by themselves. Since households with only few inhabitants are mostly located close to the city centre, it is possibly not urbanization but the urban lifestyle, which reduces energy use through short periods of presence at home.

4. What target of climate impact in the residential building sector should Altona reach for?

Altona should adopt the goals, which were set for Hamburg. The first one is a limitation of heat energy use to 40-45 kWh/m² for single family houses and to 45-55 kWh/m² for apartment buildings (cf. section 3.1.4). The second goal refers to total emissions, which are supposed to be reduced by 80 % by 2050 relative to 1990, leading to 2 t of annual CO_2 emissions per person (cf. section 2.5.4). Emissions within the sector of residential buildings will consequently need to be much lower than the limit of total emissions.

Nationally anticipated shares of renewable energy sources are between 34 % and 50 % of final energy use in 2050 (cf. section 3.5). These boundaries can give directions for Altona as well, even though conditions for the implementation of renewable energy sources need to be assessed in further detail.

However, the current situation is insufficient for effective, targeted climate action. In order to identify necessary scopes of action and to facilitate informed decision-making, the availability of enhanced data needs to be improved.

5. How can the district Authority reduce the impact on the climate of the residential building sector in Altona?

Instead of specific measures, fields of action are pointed out.

Regarding energy savings, the most effective change would be a reduction of living area per person. Other measures should refer to a higher rate of retrofits as well as a general promotion of more compact areas.

The reason for low energy consumption in dense areas could be a short utilization rate. As long as it is not clear, what impact short periods of presence have on energy use elsewhere, recommendations regarding urbanization and density cannot be made. However it should be noted, that high densities are likely to have a positive effect on mobility and land use.

In terms of carbon intensity, the share of renewable energy sources in all types of energy generation needs to be increased. Case studies should be conducted to determine the potential of solar and wind energy as well as environmental heat. Since the emission factor of the district heating grid run by Vattenfall is very high, Bezirksamt Altona should strongly support a shift from coal to other energy sources. When new local grids are implemented, low emission factors need to be ensured. Last, Bezirksamt Altona should aim to decrease the share of oil heating in private households to zero.

Above all, the introduction of a monitoring system would help to quantify current emissions and to define anticipated reductions.

6. Is the approach of analysing energy consumption and other influences on the local level effective and practical for other municipalities?

The possibility to visualize actual energy use geographically contains a great improvement to current instruments. It enables a better estimation of the current situation and needs for action. However, several uncertainties are included. A better inventory system on building data, such as heating systems, energy standards and building ages, would optimize the developed approach.

The regression analysis enables a first estimate on interdependencies, but needs further similar analyses of other years and areas to determine transferability of results. The results should only be used to forecast energy use and to decide on measures, when they are supported by additional analyses.

Generally, the analyses can be replicated according to process descriptions in the appendices. It would help to have more similar studies to increase understanding and learning of energy use in residential behaviour and to decrease the knowledge deficit.

6.4 Further research

In order to judge the usefulness of the illustrations of energy use and calculated correlations, possible reactions of people confronted with the results should be evaluated carefully. People’s attitudes and motivations should be assessed in order to create communication material and message information appropriately. The results should be in the most effective way to create awareness, increase motivation and accelerate emission reduction.

To improve the generated outcomes, similar studies need to be conducted to receive a more complete picture on energy use and its changes over time and over places. Studies in other boroughs of Hamburg could determine the geographical connection of the calculated correlations, while studies for other years in Altona could verify the significance and possible changes over the years.

The results can further be improved when uncertainties are reduced. For this purpose, data provided through ALKIS needs to be updated constantly. Information on building age, type and number of storeys should be placed on this platform, which is used by various planners. Additionally, inventories on heating systems and energy standards need to be conducted.

If the spatial analysis is supposed to be used for decision making regarding measures to be implemented, it can be overlaid with several other indicators. These would need to be defined. In addition, a complete tool for decision making would require an assessment on the suggestibility of behaviour in the different parts of Altona is needed. It would probably need to be defined by several factors, such as age, income and family status.

Since the approach represents energy use induced by inhabitants, a description of causes is possible. When data on energy use in offices or industries is available, the approach can also be used in these sectors. Again, consumption data can be displayed geographically and if desired, correlations with variables defined beforehand can be calculated. Possibly, the approach could also be used in the sectors of mobility, green space, waste and water. However, applicability and implementation of the approach in these other sectors needs to be studied first.

6.5 Outlook

The residential building stock remains a challenge but also provides a great opportunity for energy and emission reduction. The opportunities and challenges are determined by future development. Several trends are taking place and are likely to have an impact on the residential building sector.

Currently, statements of commitment and individual measures are rather blurry. They do not seem to be sufficient to decrease energy use and resulting emissions quickly. Alternatively, a universal monitoring system could define needs for required improvements more precisely and raise pressure for mitigation action in the residential building sector. Rising pressure could also lead to stricter measures, such as the obligation for retrofits. If such systems were introduced, mitigation action could accelerate in the future.

Another unanswered question of general orientation is the handling of electricity use. Currently, the emission factor of electricity is very high. If potentials of a decarbonisation of electricity are made use of, in the future the use of electricity will present a climate friendly option. Electricity use could automatically be increased due to global warming. Looking at the increasing number of hot days in Hamburg, the amount of air conditioning is likely to increase. This will lead to higher electricity uses.

Lastly, the trend of digitilisation has been introduced to the residential building sector. Some studies have shown positive results of transparent recordings of energy consumption, leading to competition between neighbours. If further studies find evidence of positive effects on energy saving through digitilisation and if the implementation was simplified further, so-called smart homes could possibly also find a place in the existing building stock.

As shown, future potential in the decrease of energy use in private households exist, which in turn would lead to a reduction of GHG emissions.

7 References

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Appendices

Appendix A

Determination of GHG emissions of new buildings per living area for the phases before, during and after operation.

Building	Construction, energy standard	Before Use	Use		End of Life
			Operational	Fabric, Finishing, Technical Equipment	
		kg CO_2e/m²	kg CO_2e/m²/a	kg CO_2e/m²/a	kg CO_2e/m²
No. 1	Solid, Passive House	530.0 (=10.6*50)	35.6	3.0	102.0 (=2.04*50)
No. 2	Timber, Low energy	382.5 (=7.65*50)	50.8	2.8	65.5 (=1,31*50)
No. 3	Timber, Low energy	434.5 (=8.69*50)	45.6	5.5	123.0 (=2,46*50)
No. 4	Solid, Low energy	530.0 (=10.6*50)	39.9	6.4	136.0 (=2.72*50)
No. 5	Solid, Low energy	565.0 (=11.3*50)	45.9	5.0	138.5 (=2.77*50)
Average All		**488.4**	**43.6**	**4.5**	**113.0**
Average Solid Construction		**541.7**	**40.5**	**4.8**	**125.5**
Average Low energy		**478.0**	**45.6**	**4.9**	**115.8**

Table 28: GHG Emissions per Living Area of five Residential Buildings in Austria before, during and after Use (adapted from Passer et al., 2012, p. 1125-1126)

Since the reference study period was 50 years (Passer et al., 2012, p. 1119), the values for the phases before and after use are multiplied by this period. This way, emissions are given in total per square metre of erected living area.

Appendix B

Explanation of Selection of Residential Buildings from the ALKIS geodatabase SDP_2016

In the attribute table of the layer "Flaechenfoermige Gebaeude und Bauteile" there is a column called "BEZGFK", which stands for "Bezeichnung Gebäudefunktion" (in English: designation of building function). A short description of each function can be found at adV (2015) at page 212 – 224.

All buildings (polygons), which carried one of the titles listed in Table 29 were selected as residential buildings. In total, these were 35,182 buildings. The table also shows the share of each kind of residential buildings. The table also shows the share of each kind of residential building in all buildings in Altona. 90 % of all buildings are pure residential buildings or dwellings. All other buildings exhibit also other uses besides living.

BEZGFK	English meaning	Share in all residential buildings
Gebäude für Gewerbe und Industrie mit Wohnen	Building for business and industry with habitation	0.12 %
Gebäude für Handel und Dienstleistung mit Wohnen	Building for trade and services with habitation	0.57 %
Gebäude für öffentliche Zwecke mit Wohnen	Building for public purposes with habitation	0.01 %
Gemischt genutztes Gebäude mit Wohnen	Building for mixed use with habitation	5.10 %
Land- und forstwirtschaftliches Wohn- und Betriebsgebäude	Residential and company building for agriculture and forestry	0.05 %
Land- und forstwirtschaftliches Wohngebäude	Residential building for agriculture and forestry	0.04 %
Wohn- und Betriebsgebäude	Residential and company building	0.00 %
Wohn- und Bürogebäude	Residential and office building	0.00 %

BEZGFK	English meaning	Share in all residential buildings
Wohn- und Geschäftsgebäude	Residential and commercial building	0.03 %
Wohn- und Verwaltungsgebäude	Residential and administration building	0.01 %
Wohngebäude	Residential building	7.09 %
Wohngebäude mit Gemeinbedarf	Residential building with communal use	0.03 %
Wohngebäude mit Gewerbe und Industrie	Residential building with business and industry	0.63 %
Wohngebäude mit Handel und Dienstleistungen	Residential building with trade and services	2.89 %
Wohnheim	Dormitory	0.61 %
Wohnhaus	Dwelling	82.82 %

Table 29: Designation of building functions taken as residential buildings (Author, 2017)

Appendix C

Explanation of Calculation of Building Surface and Volume

The following parameters are given:

A = Floor area (Polygon area from ArcGIS)

U = Building extent (Polygon length from ArcGIS)

OG = number of full storeys above ground (Attribute from polygon in ArcGIS)

In order to calculate the exact building surface (S) and volume (V), all other parameters such as height, edge lengths and exact shape of roof top with all overhangs would be needed. Since these measurements are not available, calculation was made with an assumed average storey height (h) of 3.50 m and the given extent. The results are consequently not precise, but allow a rough idea of the proportions of each building.

The following table presents the used formulas. The calculation distinguishes between a flat roof and other roof types.

Designation	English meaning	Calculation of S	Calculation of V
Flachdach	Flat roof	2*A + U*OG*h	A*OG*h
Satteldach	Saddle roof	A + h*U*(h+2)	A*h *(OG+0.5)
Walmdach	Hip roof		
Krüppelwalmdach	Half-hip roof		
Mansardendach	Mansard roof		
Zeltdach	Tent roof		
Kuppeldach	Dome roof		
Bogendach	Arch roof		
Turmdach	Turret roof		
Mischform	Hybride		

Table 30: Calculation of Building Surface and Volume (Author, 2017)

Appendix D

Climate Factors of all Districts in Altona from 2008 to 2017

The following graph shows the climate factors for the postal codes 22525, 22547, 22549, 22559, 22587, 22589, 22605, 22607, 22609, 22761, 22763, 22765, 22767 and 22769. The calculated mean represents the average for the borough Altona as used in this paper. It was 1.10 in the year 2015, meaning that 2015 was a warm year.

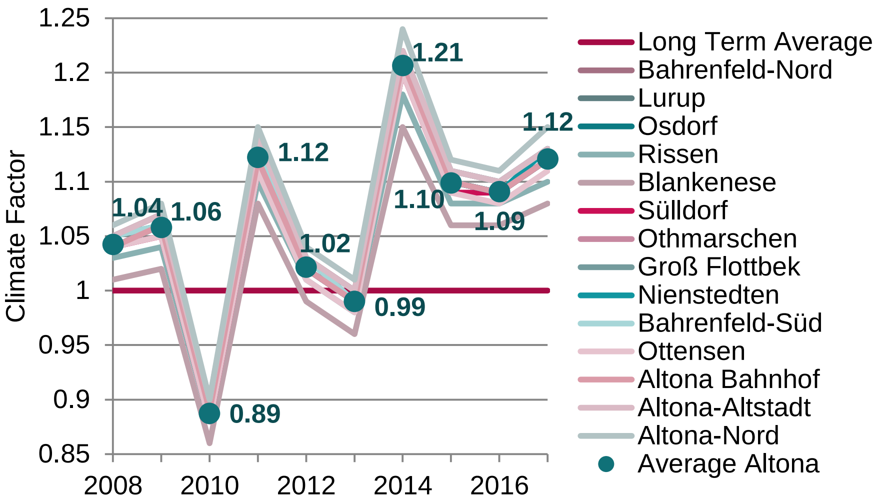


Figure 126: Climate Factors for the Districts in Altona from 2008 to 2017 (adapted from German Meteorological Service, 2018)

Appendix E

Data Compilation of Inhabitants in Altona

The population data from the Statistikamt Nord for the year 2015 could not be used the way it is, because the total number of inhabitants per statistical area includes newly migrated people living in collective, temporary accommodations. Since these accommodations are not included in data on energy use, it would lead to a wrong result if both data sets were matched.

Instead, Andreas Kaiser from BSW (Behörde für Stadtentwicklung und Wohnen) provided a new dataset counting only the inhabitants in private households. In addition, Annett Jackisch from Statistikamt Nord sent the number of inhabitants aged 15 to 64 per Statistical Area. Both data sets were sent on 05.06.2018.

Appendix F

Share of GFA with assigned Building Age and Type

In the study conducted by ecofys, not all buildings were labelled with an age group and a typology. The following table presents the share of GFA per Statistical Area (StatGeb), which has an assigned age group and typology. The areas coloured in red were later excluded from the analysis in this paper because they included less than 10 residential buildings (cf. Appendix H and Appendix I).

StatGeb	District	Share of GFA with age group	Share of GFA with typology
21001	Altona-Altstadt	68%	72%
21002	Altona-Altstadt	76%	68%
21003	Altona-Altstadt	94%	93%
21004	Altona-Altstadt	76%	76%
21005	Altona-Altstadt	77%	77%
21006	Altona-Altstadt	98%	98%
21007	Altona-Altstadt	38%	37%
21008	Altona-Altstadt	68%	68%
21009	Altona-Altstadt	63%	63%
21010	Altona-Altstadt	69%	70%
21011	Altona-Altstadt	63%	59%
21012	Altona-Altstadt	68%	68%
22001	Sternschanze	72%	65%
22002	Sternschanze	69%	69%
22003	Sternschanze	74%	72%
22004	Sternschanze	39%	39%
23001	Altona-Nord	85%	84%
23002	Altona-Nord	89%	89%
23003	Altona-Nord	100%	100%

StatGeb	District	Share of GFA with age group	Share of GFA with typology
23004	Altona-Nord	71%	76%
23005	Altona-Nord	68%	68%
23006	Altona-Nord	87%	87%
23007	Altona-Nord	84%	85%
23008	Altona-Nord	0%	0%
23009	Altona-Nord	83%	81%
23010	Altona-Nord	93%	93%
23011	Altona-Nord	89%	89%
24001	Ottensen	90%	88%
24002	Ottensen	86%	80%
24003	Ottensen	70%	70%
24004	Ottensen	100%	100%
24005	Ottensen	99%	100%
24006	Ottensen	95%	93%
24007	Ottensen	83%	83%
24008	Ottensen	77%	76%
24009	Ottensen	87%	87%
24010	Ottensen	44%	44%
24011	Ottensen	97%	98%
24012	Ottensen	97%	97%
24013	Ottensen	78%	78%
24014	Ottensen	84%	84%
24015	Ottensen	47%	63%
25001	Bahrenfeld	55%	61%
25002	Bahrenfeld	0%	0%
25003	Bahrenfeld	98%	98%
25004	Bahrenfeld	65%	74%
25005	Bahrenfeld	99%	99%
25006	Bahrenfeld	87%	87%
25007	Bahrenfeld	81%	82%
25008	Bahrenfeld	58%	50%
25009	Bahrenfeld	40%	88%
25010	Bahrenfeld	54%	64%
25011	Bahrenfeld	95%	96%
25012	Bahrenfeld	93%	93%
25013	Bahrenfeld	65%	58%
25014	Bahrenfeld	82%	82%
25015	Bahrenfeld	93%	89%
25016	Bahrenfeld	51%	72%
25017	Bahrenfeld	69%	66%
25018	Bahrenfeld	100%	97%
26001	Groß Flottbek	92%	91%
26002	Groß Flottbek	91%	87%

StatGeb	District	Share of GFA with age group	Share of GFA with typology
26003	Groß Flottbek	91%	92%
26004	Groß Flottbek	85%	88%
26005	Groß Flottbek	92%	90%
27001	Othmarschen	85%	88%
27002	Othmarschen	90%	84%
27003	Othmarschen	31%	39%
27004	Othmarschen	54%	53%
27005	Othmarschen	63%	94%
27006	Othmarschen	88%	90%
27007	Othmarschen	90%	93%
27008	Othmarschen	71%	71%
27009	Othmarschen	87%	84%
28001	Lurup	93%	98%
28002	Lurup	97%	97%
28003	Lurup	89%	97%
28004	Lurup	83%	76%
28005	Lurup	97%	98%
28006	Lurup	78%	85%
28007	Lurup	67%	68%
28008	Lurup	100%	100%
28009	Lurup	80%	81%
28010	Lurup	92%	94%
28011	Lurup	14%	14%
28012	Lurup	66%	78%
28013	Lurup	100%	100%
28014	Lurup	73%	76%
28015	Lurup	78%	86%
28016	Lurup	95%	95%
29001	Osdorf	95%	98%
29002	Osdorf	100%	96%
29003	Osdorf	100%	100%
29004	Osdorf	99%	99%
29005	Osdorf	85%	87%
29006	Osdorf	97%	98%
29007	Osdorf	80%	81%
29008	Osdorf	82%	84%
29009	Osdorf	68%	89%
29010	Osdorf	86%	93%
29011	Osdorf	90%	92%
29012	Osdorf	71%	74%
29013	Osdorf	88%	94%
30001	Nienstedten	80%	88%
30002	Nienstedten	92%	93%

StatGeb	District	Share of GFA with age group	Share of GFA with typology
30003	Nienstedten	75%	76%
30004	Nienstedten	91%	92%
31001	Blankenese	73%	86%
31002	Blankenese	88%	89%
31003	Blankenese	76%	84%
31004	Blankenese	78%	80%
31005	Blankenese	87%	87%
31006	Blankenese	93%	93%
32001	Iserbrook	83%	85%
32002	Iserbrook	84%	86%
32003	Iserbrook	75%	86%
32004	Iserbrook	85%	87%
32005	Iserbrook	71%	73%
33001	Sülldorf	23%	26%
33002	Sülldorf	82%	100%
33003	Sülldorf	87%	88%
33004	Sülldorf	86%	87%
33005	Sülldorf	97%	97%
34001	Rissen	9%	25%
34002	Rissen	70%	73%
34003	Rissen	83%	82%
34004	Rissen	84%	88%
34005	Rissen	96%	96%
34006	Rissen	81%	76%
34007	Rissen	77%	72%
34008	Rissen	68%	75%

Table 31: Share of GFA with assigned Building Age and Type (Author, 2017)

Appendix G

Comparison of calculated GFA with Living Area per Inhabitant in Districts

Living area is statistically recorded at the level of districts. With the help of ALKIS the GFA was calculated at the level of Statistical Areas. Living area is approximately 80 % of GFA. In consequence, the values of GFA can be multiplied by a factor to calculate living area at the level of Statistical Areas. As the following table shows, in more urban areas, the factor is lower than 0.80, while in suburban areas the factor is higher. The chosen factors and the resulting calculated living area per person in comparison with the given one are shown below.

District	Calculated GFA per inhabitant	Factor	Calculated Living Area per Inhabitant (Factor * GFA)	Living Area per Inhabitant
Altona-Altstadt	59.0	0.65	38.3	38.3
Sternschanze	60.8	0.70	42.6	43.5
Altona-Nord	48.5	0.80	38.8	39.1
Ottensen	56.4	0.75	42.3	42.2
Bahrenfeld	49.5	0.80	39.6	40.8
Groß Flottbek	59.4	0.85	50.5	49.3
Othmarschen	65.1	0.85	55.3	54.5
Lurup	43.1	0.85	36.6	37.8
Osdorf	50.5	0.85	42.9	42.2
Nienstedten	67.3	0.90	60.6	58.9
Blankenese	71.8	0.80	57.4	58.5
Iserbrook	50.1	0.85	42.6	42.1
Sülldorf	50.7	0.90	45.6	45.8
Rissen	56.2	0.80	44.9	49.9

Table 32: Comparison ofLiving Area with calculated GFA (Author, 2018)

Appendix H

Data Compilation of Electricity Use in Altona

The data on electricity use for the years 2014 and 2015 was sent on 09.04.2017 by Thimo Schlicht from Stromnetz Hamburg GmbH. It was split by street and type. The three types given were industry, households and heating. The latter includes electricity used by heat pumps and night storage heaters. However, it was not separated by industry and households, which is why it cannot be used in this paper.

Some streets run through several Statistical Areas. To distribute electricity consumption fairly, the amount was split by the share of the calculated gross floor area of residential buildings of a street in every Statistical Area it ran through.

The following Statistical Areas were excluded from the analysis:

Statistical Area	District	Reason for Exclusion
22004	Sternschanze	Unusual high electricity use of 3555 kWh/capita
23008	Altona-Nord	Less than 40 inhabitants, Less than 10 residential buildings
25002	Bahrenfeld	Less than 40 inhabitants, Less than 10 residential buildings

Statistical Area	District	Reason for Exclusion
25005	Bahrenfeld	Less than 10 residential buildings
25009	Bahrenfeld	Less than 10 residential buildings

Table 33: Exclusion of Statistical Areas from the Analysis of Electricity Use (Author, 2018)

This leaves the analysis with 126 Statistical Areas.

Appendix I

Data Compilation of Heat Energy Use in Altona

District Heat by Vattenfall Europe Sales GmbH

Sent on 12.03.2018 by Dr.-Ing. Helmut Adwiraah (project engineer at Averdung Ingenieurgesellschaft mbH).

The data was sent by a staff member from Vattenfall Europe Sales GmbH (in the following called Vattenfall) for the years 2014 – 2016. It was divided by streets and profiles. For the analysis only energy use in 2015 was used. The profile "Wohnzwecke größer 80 %" (residential purposes larger than 80 %) was selected and used for the analysis. The data was converted from a level of streets to a level of Statistical Areas by the share of gross floor area of residential buildings.

By URBANA Energiedienste GmbH

Sent on 20.12.2017 by Dr.-Ing. Helmut Adwiraah (project engineer at Averdung Ingenieurgesellschaft mbH).

Instead of sending the energy use, Thilo Ruch, a staff member of URBANA Energiedienste GmbH (in the following called Urbana), sent the grid feed in MWh. In order to calculate the energy, which reached the consumer, losses had to be subtracted. As a comparison, losses of HanseWerk Natur GmbH in 2015 had been 15 %. Since the grids operated by Urbana are smaller than the ones from HanseWerk Natur GmbH, their losses were assumed to be 10 %. Energy use was consequently calculated by taking the grid feed and reducing it to 90 %.

Urbanas grids are small enough to all stay within a statistical area. Their grids are to be found in the areas 24001 (Ottensen), 25004 and 25007 (Bahrenfeld) and 27004 (Othmarschen). They serve only private households, except in Othmarschen were a hospital is the only commercial user. Because of data protection, the hospital's energy use cannot be excluded. Statistical area 27004 is therefore excluded from the data analysis.

By HanseWerk Natur GmbH

Sent on 09.04.2018 by Dr.-Ing. Helmut Adwiraah (project engineer at Averdung Ingenieurgesellschaft mbH).

The data were sent on a level of streets and consequently had to be converted to a level of Statistical Areas. Again, it was being done by the share of gross floor area, but also by comparing the consumption data to the grid of HanseWerk Natur GmbH, which was sent by Martin Schlaug from HanseWerk Natur GmbH on 20.06.2018 (Schlaug, 2018).

<u>Gas</u>

Sent on 29.05.2018 by Malte van Haastrecht (at Gasnetz Hamburg GmbH).

The data shows heat energy consumption of private households in kWh from 2014-2016 in every Statistical Area. Data of areas with less than 5 points of use is not shown. A point of use can be one or several households. This concerns the following statistical areas: 23008 (Altona-Nord), 25002 (Bahrenfeld) and 28013, 29002, 29003 and 29006 (Lurup). These areas are therefore excluded from the analysis.

All in all, the following Statistical Areas were excluded:

Statistical Area	District	Reason for Exclusion
23008	Altona-Nord	Less than 40 inhabitants, Less than 10 residential buildings
25001	Bahrenfeld	Unusual high heat energy use of 23,868 kWh/capita
25002	Bahrenfeld	Less than 40 inhabitants, Less than 10 residential buildings
25005	Bahrenfeld	Less than 10 residential buildings
25009	Bahrenfeld	Less than 10 residential buildings
27004	Othmarschen	Data from Urbana includes the hospital
28013	Lurup	No data on gas use
29002	Osdorf	No data on gas use
29003	Osdorf	No data on gas use
29006	Osdorf	No data on gas use

Table 34: Exclusion of Statistical Areas from the Analysis of Heat Energy Use (Author, 2018)

This leaves the analysis with 121 Statistical Areas.

Energy consumption for heating of all different providers was then combined for every Statistical Area.

As shown in Appendix D, the climate factor in the borough Altona was 1.10 in 2015. The data on heat energy use in this year consequently was multiplied by this factor.

Appendix J

Adjusted Stromspiegel 2016

The so-called Stromspiegel presents average electricity use for households in Germany. It takes into account the building type, the number of inhabitants and the generation of hot water.

The Stromspiegel is published by "co2online gemeinnützige Beratungsgesellschaft mbH" and the most recent version is available on their website at www.stromspiegel.de. It was created for the years 2014, 2016 and 2017. Since the reference year in this paper is 2015, the Stromspiegel for the year 2016 was used. It was sent via email by Boris Demrovski (2018).

The table below presents the modified Stromspiegel 2016. The unit was changed to kWh per inhabitant to visualize the changes in energy use per person. The amounts were rounded to the nearest tens.

Type of building	Number of inhabitants	Hot water not generated by electricity	Hot water generated by electricity
Single family /semi-detached house	1	1,500 – 4,200	1,800 – 6,000
	2	1,050 – 2,250	1,250 – 3,250
	3	870 – 1,830	1,070 – 2,500
	4	750 – 1,500	880 – 2,050
	5+	< 700 – 1,600	< 900 – 2,260
Apartment building	1	800 – 2,500	1,200 – 3,400
	2	650 – 1,600	1,000 – 2,200
	3	600 – 1,330	900 – 2,000
	4	500 – 1,150	780 – 1,780
	5+	< 480 – 1,200	< 660 – 1,800

Table 35: Typical Annual Electricity Use per Capita (kWh) in Germany (adapted from Demrovski, 2018)

Appendix K

Simple Linear Regression Analysis for Electricity Use: Comparison of the r-value (correlation) and the p-value (significance) for all independent Variables at the Level of Statistical Areas with those of the District level

The table shows that on a higher level (districts) correlation for most variables increases, but significance decreases. In all models the significance is higher on the lower level (Statistical Areas).

X	Key point	Statistical Areas		Districts	
		r	p	r	p
X_{01}	inhab/hh	0.21	0.016	0.44	0.119
X_{02}	inhab/ha	-0.35	0.000	-0.37	0.191
X_{03}	single p hh	-0.24	0.006	-0.41	0.148
X_{04}	hh/building	-0.33	0.000	-0.37	0.198
X_{05}	hh/ha	-0.32	0.000	-0.36	0.211
X_{06}	GFA/area	-0.27	0.002	-0.29	0.318
X_{07}	GFA/inhab	0.55	0.000	0.82	0.000
X_{08}	children	0.06	0.476	0.34	0.235
X_{09}	≥65 yrs	0.44	0.000	0.49	0.079
X_{10}	employm.	-0.54	0.000	-0.85	0.000
X_{11}	unempl.	-0.43	0.000	-0.76	0.002
X_{12}	social h.	-0.25	0.005	-0.64	0.014
X_{13}	N° storeys	-0.29	0.001	-0.29	0.322
X_{14}	AV ratio	0.25	0.005	0.10	0.734
X_{age1}	…-1918	0.08	0.380	0.14	0.631
X_{age2}	1919-1948	0.20	0.024	0.35	0.216
X_{age3}	1949-1957	0.06	0.519	030	0.303
X_{age4}	1958-1968	-0.08	0.387	-0.34	0.231
X_{age5}	1969-1978	-0.20	0.029	-0.29	0.316
X_{age6}	1979-1983	0.05	0.565	0.26	0.371

X	Key point	Statistical Areas		Districts	
		r	p	r	p
X_{age7}	1984-1994	-0.02	0.845	-0.41	0.145
X_{age8}	1995-…	-0.02	0.844	0.27	0.359
X_{typ1}	EFH/DHH	0.46	0.000	0.75	0.002
X_{typ2}	RH	-0.05	0.556	-0.23	0.425
X_{typ3}	MFH single	0.38	0.000	0.79	0.001
X_{typ4}	MFH group	-0.16	0.072	-0.22	0.443
X_{typ5}	MFH block	-0.39	0.000	-0.82	0.000
X_{typ6}	MFH high-r	-0.13	0.144	-0.66	0.290

Table 36: Comparison of Correlation and Significance of Models of different Levels for Electricity Use (Author, 2018)

Simple Linear Regression Analysis for Heat Energy Use: Comparison of the r-value (correlation) and the p-value (significance) for all independent variables at the level of Statistical Areas with those of the district level

The table shows that on a higher level (districts) correlation for most variables increases, but significance decreases. In all models the significance is higher on the lower level (Statistical Areas).

X	Key point	Statistical Areas		Districts	
		r	p	r	p
X_{01}	inhab/hh	0.32	0.000	0.56	0.039
X_{02}	inhab/ha	-0.43	0.000	-0.43	0.121
X_{03}	single p hh	-0.30	0.001	-0.51	0.060
X_{04}	hh/building	-0.45	0.000	-0.48	0.083
X_{05}	hh/ha	-0.42	0.000	-0.44	0.117
X_{06}	GFA/area	-0.33	0.000	-0.34	0.232
X_{07}	GFA/inhab	0.51	0.000	0.79	0.001
X_{08}	children	0.16	0.074	0.50	0.070
X_{09}	≥65 yrs	0.38	0.000	0.50	0.067
X_{10}	employm.	-0.57	0.000	-0.82	0.000

X	Key point	Statistical Areas		Districts	
		r	p	r	p
X_{11}	unempl.	-0.39	0.000	-0.66	0.010
X_{12}	social h.	-0.35	0.000	-0.50	0.066
X_{13}	N° storeys	-0.37	0.000	-0.39	0.168
X_{14}	AV ratio	0.32	0.000	0.20	0.490
X_{age1}	…-1918	0.14	0.119	-0.04	0.888
X_{age2}	1919-1948	0.01	0.915	0.32	0.266
X_{age3}	1949-1957	0.02	0.833	0.26	0.376
X_{age4}	1958-1968	-0.11	0.230	-0.17	0.665
X_{age5}	1969-1978	-0.10	0.282	-0.13	0.657
X_{age6}	1979-1983	0.11	0.248	0.11	0.698
X_{age7}	1984-1994	-0.05	0.575	-0.43	0.121
X_{age8}	1995-…	0.03	0.723	0.15	0.599
X_{typ1}	EFH/DHH	0.49	0.000	0.72	0.003
X_{typ2}	RH	0.12	0.195	-0.09	0.757
X_{typ3}	MFH single	0.43	0.000	0.77	0.001
X_{typ4}	MFH group	-0.19	0.041	-0.40	0.157
X_{typ5}	MFH block	-0.53	0.000	-0.67	0.008
X_{typ6}	MFH high-r	-0.08	0.364	-0.30	0.290

Table 37: Comparison of Correlation and Significance of Models of different Levels for Heat Energy Use (Author, 2018)

Appendix L

Scatterplots of Models with Y_{01} with no Significance

Figure 127: Scatterplot of Electricity Use per Capita (Y_{01}) and Share of Households with Children (X_{08}) (Author, 2018)

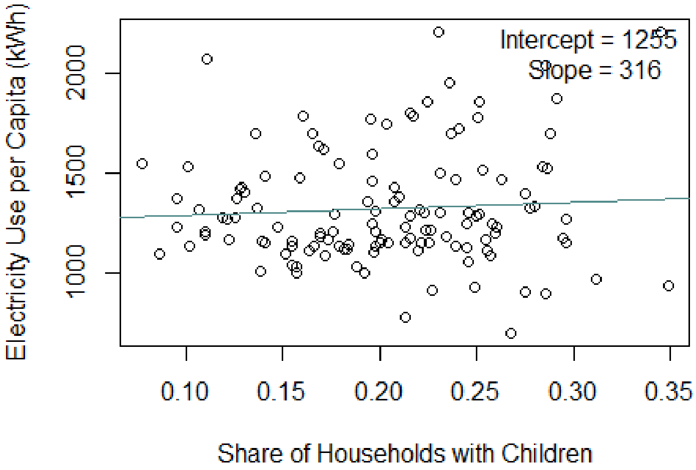
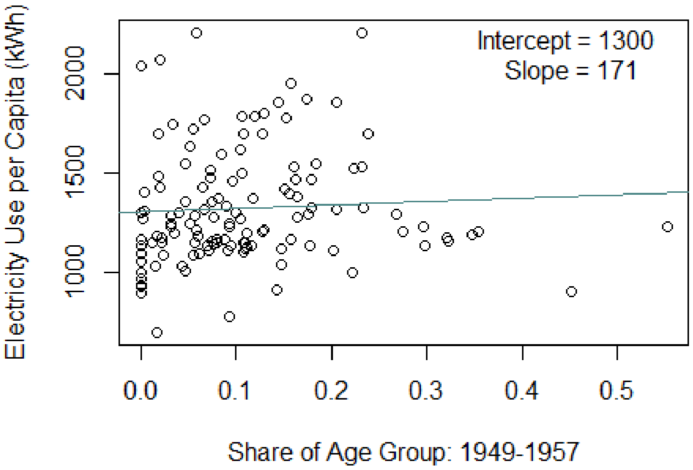


Figure 129: Scatterplot of Electricity Use per Capita (Y_{01}) and Age Group 1 (before 1918) (X_{age1}) (Author, 2018)

Figure 128: Scatterplot of Electricity Use per Capita (Y_{01}) and Age Group 3 of 1949-1957 (X_{age3}) (Author, 2018)



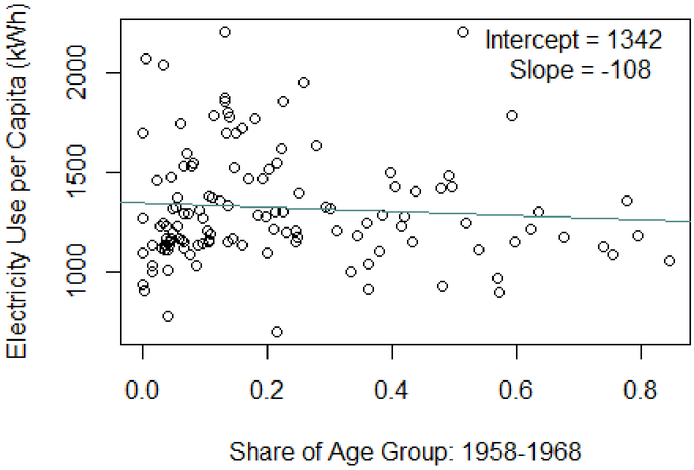


Figure 131: Scatterplot of Electricity Use per Capita (Y_{01}) and Age Group 4 (1958-1968) (X_{age4}) (Author, 2018)

Figure 130: Scatterplot of Electricity Use per Capita (Y_{01}) and Age Group 6 (1979-1983) (X_{age6}) (Author, 2018)

Figure 132: Scatterplot of Electricity Use per Capita (Y_{01}) and Age Group 7 (84-1994) (X_{age7}) (Author, 2018)

Figure 133: Scatterplot of Electricity Use per Capita (Y_{01}) and Age Group 8 (after1995) (x_{age8}) (Author, 2018)

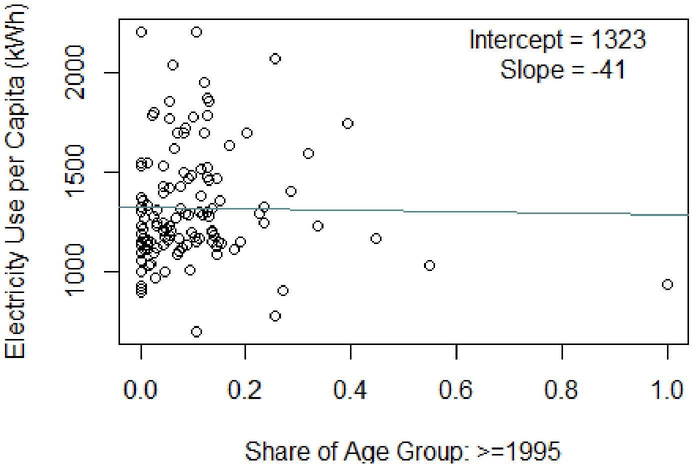


Figure 134: Scatterplot of Electricity Use per Capita (Y_{01}) and Share of Terraced Houses (X_{type2}) (Author, 2018)

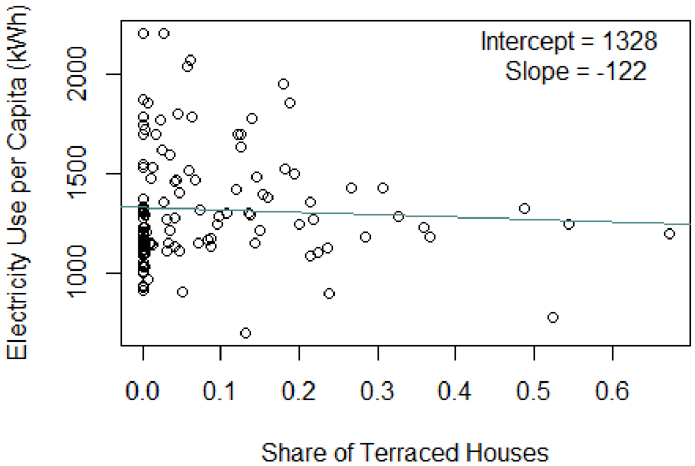
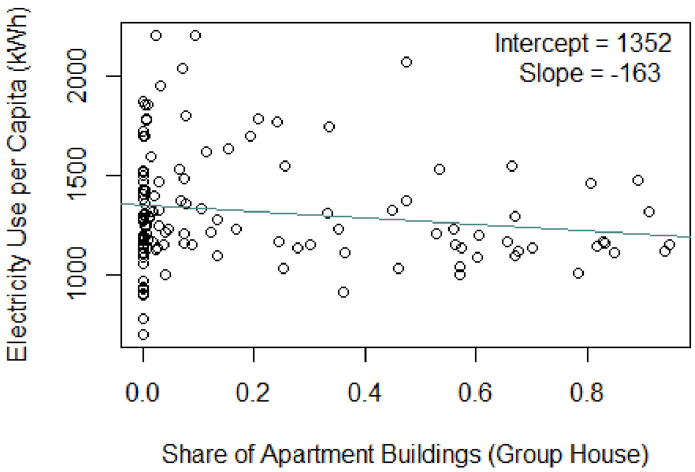


Figure 135: Scatterplot of Electricity Use per Capita (Y_{01}) and Share of Apartment Buildings (Groupe) (X_{typ4}) (Author, 2018)



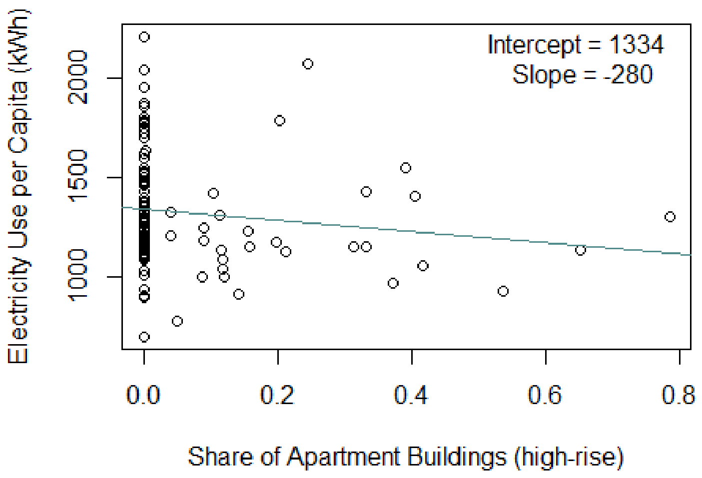


Figure 136: Scatterplot of Electricity Use per Capita (Y_{01}) and Share of Apartment Buildings (High-rise) (X_{typ6}) (Author, 2018)

Appendix M

Scatterplots of Models with Y_{02} with no Significance

Figure 137: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Share of Households with Children (X_{08}) (Author, 2018)

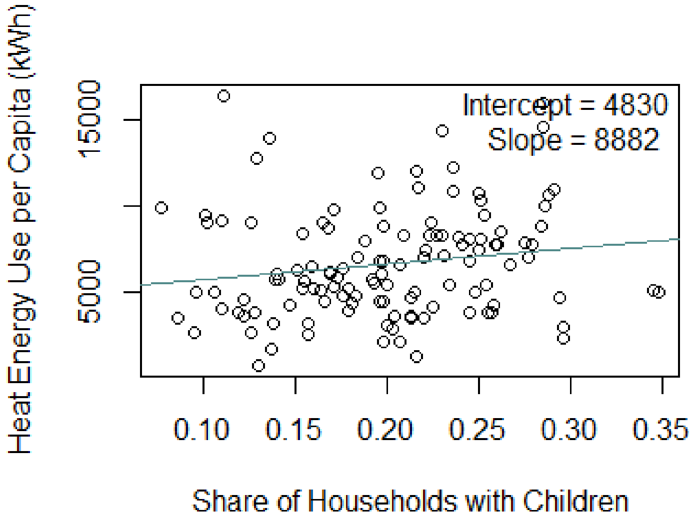
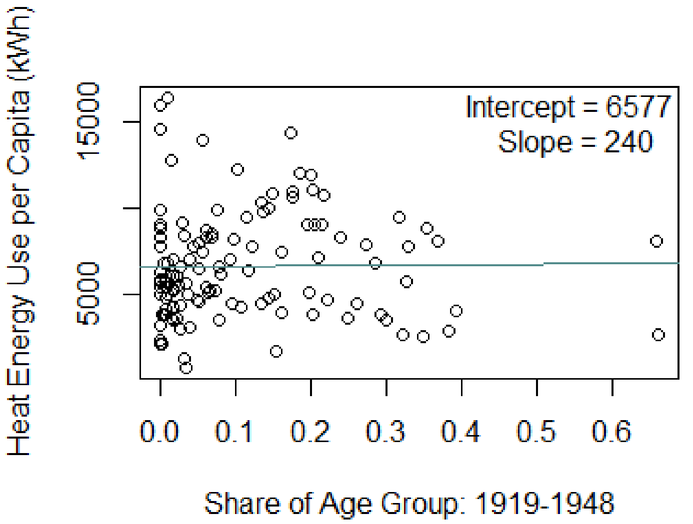


Figure 138: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Age Group 1 (before 1918) (X_{age1}) (Author, 2018)

Figure 139: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Age Group 2 (1919-1948) (X_{age2}) (Author, 2018)



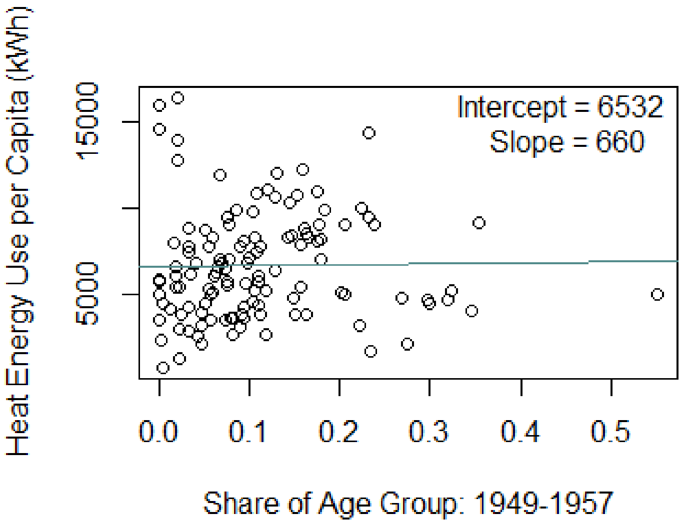


Figure 140: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Age Group 3 (1949-1957) (X_{age3}) (Author, 2018)

Figure 142: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Age Group 4 (1958-1968) (X_{age4}) (Author, 2018)

Figure 141: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Age Group 6 (1969-1978) (X_{age6}) (Author, 2018)

Figure 143: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Age Group 6 (1979-1983) (X_{age6}) (Author, 2018)

Figure 144: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Age Group 7 (1984-1994) (X_{age7}) (Author, 2018)

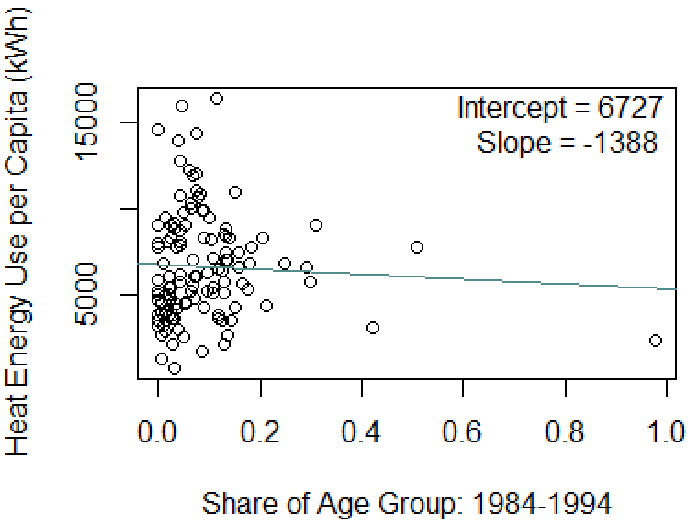
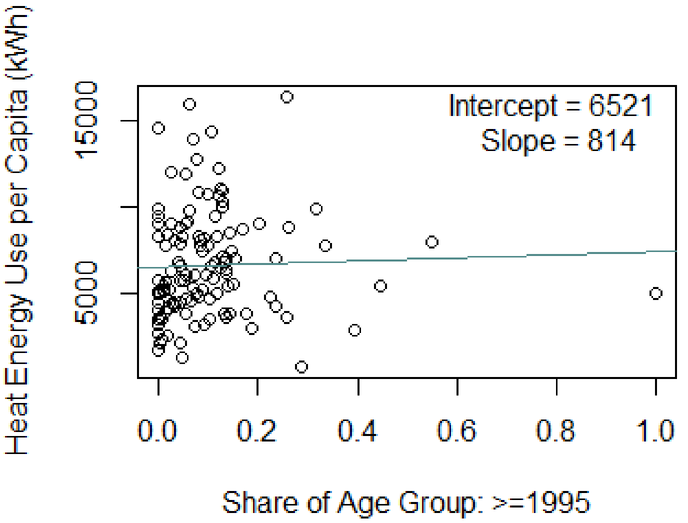


Figure 145: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Age Group 8 (after 1995) (X_{age8}) (Author, 2018)



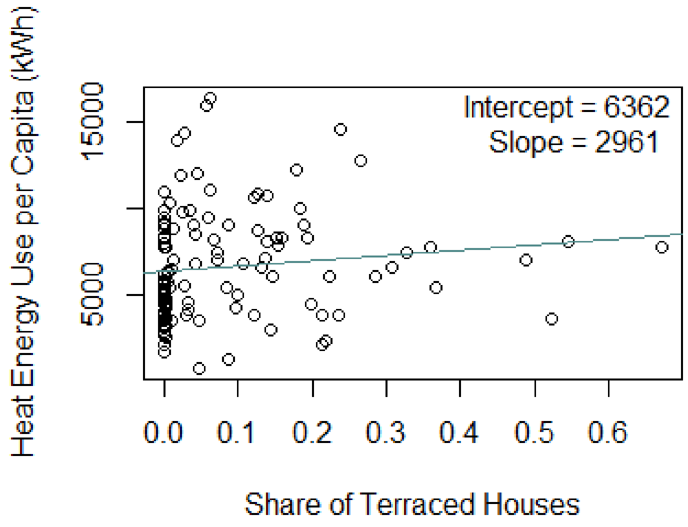


Figure 146: Scatterplot of Heat Energy Use per Capita (Y_{02}) and Share of Terraced Houses (X_{typ2}) (Author, 2018)

Figure 147: Scatterplot of Heat Energy Use per Capita (Y_{02}) and High-rise Apartment Buildings (X_{typ8}) (Author, 2018)

Appendix N

Simple Linear Regression Analysis for the Sum of Electricity (Y_{01}) and Heat Energy Use (Y_{02})

The following table gives the correlation r, the coefficient of determination r² and the significance p and highlights the meaningful ones. Only the Statistical Areas were included, which do not hold any inaccuracies for neither electricity nor heat energy use.

X	Key point	Correlation r		r²	Significance p	
X_{01}	inhab/hh	0.33	moderate	10.75 %	0.000	very high
X_{02}	inhab/ha	-0.43	moderate	18.79 %	0.000	very high
X_{03}	single p hh	-0.32	moderate	9.96 %	0.000	very high
X_{04}	hh/building	-0.46	moderate	20.80 %	0.000	very high
X_{05}	hh/ha	-0.42	moderate	18.03 %	0.000	very high
X_{06}	GFA/area	-0.34	moderate	11.34 %	0.000	very high
X_{07}	GFA/inhab	0.53	moderate	28.25 %	0.000	very high
X_{08}	children	0.16	weak	2.72 %	0.072	barely
X_{09}	≥65 yrs	0.40	moderate	15.70 %	0.000	very high
X_{10}	employm.	-0.59	moderate	35.01 %	0.000	very high
X_{11}	unempl.	-0.41	moderate	17.19 %	0.000	very high
X_{12}	social h.	-0.35	moderate	12.28 %	0.000	very high
X_{13}	N° storeys	-0.39	moderate	14.95 %	0.000	very high
X_{14}	AV ratio	0.34	moderate	11.31 %	0.000	very high
X_{age1}	…-1918	0.14	weak	1.83 %	0.140	no
X_{age2}	1919-1948	0.03	weak	0.09 %	0.749	no
X_{age3}	1949-1957	0.03	weak	0.09 %	0.745	no
X_{age4}	1958-1968	-0.10	weak	1.08 %	0.258	no
X_{age5}	1969-1978	-0.11	weak	1.17 %	0.240	no
X_{age6}	1979-1983	0.10	weak	0.98 %	0.282	no
X_{age7}	1984-1994	-0.05	weak	0.30 %	0.554	no
X_{age8}	1995-…	0.02	weak	0.05 %	0.810	no

X	Key point	Correlation r		r^2	Significance p	
X_{typ1}	EFH/DHH	0.51	moderate	25.95 %	0.000	very high
X_{typ2}	RH	0.11	weak	1.21 %	0.231	no
X_{typ3}	MFH single	0.44	moderate	19.03 %	0.000	very high
X_{typ4}	MFH group	-0.21	weak	4.24 %	0.024	moderate
X_{typ5}	MFH block	-0.53	moderate	27.90 %	0.000	very high
X_{typ6}	MFH high-r	-0.08	weak	0.72 %	0.357	no

Appendix O

Transcript of the Interview with Martina Nitzl

Time: 08.08.2018 at 11.30 am

Place: Bezirksamt Altona, Jessenstraße 1-2 in Hamburg

Language: German

Interview partner: Martina Nitzl works at Bezirksamt Altona and is the contact person in the administration for the climate protection concept of Altona.

Annika Stein (AS): So, auf jeden Fall vielen Dank für die Zeit, die du dir nimmst.

Martina Nitzl (MN): Gerne.

AS: Wir haben ja schon einige Fragen vorliegen und die werden wir einfach durchgehen. Und das sollte hoffentlich maximal 30 Minuten dauern. Genau, ich habe dir gerade gezeigt, welche Ergebnisse vorläufig herausgekommen sind bei der Untersuchung der Energieverbräuche in den Altonaer Haushalten und habe dir die gerade gezeigt. Und ich würde gerne wissen, ob dir die neu sind oder ob dir die bereits bekannt sind.

MN: Die Zahlen sind mir im Detail natürlich überhaupt nicht bekannt. Und sind wirklich neue Ergebnisse, ... Die Ergebnisse, was herausgekommen ist, die Bereiche, die eindeutig blau und rot sind, das konnte man sich im Vorfeld allein auch anhand der Strukturdaten quasi denken. Die Wahrscheinlichkeit konnte man schon relativ hoch einschätzen.

AS: Und war dir die Bedeutung des Wohngebäudesektors hinsichtlich der Emissionen klar?

MN: Ja, dass es eine Bedeutung hat, ist mir klar. Dass die Bedeutung auch hoch ist, aber wiederum in Relation zu Verkehr und zu auch Nicht-Wohnnutzungen eben auch nur ein Anteil ist, war mir im Grunde auch klar. Also, dass es ein Anteil von vielen ist.

AS: Dann haben wir uns ja die Korrelationen angeguckt und die Ergebnisse gerade betrachtet. Das, was dabei herausgekommen ist, ist das für dich so logisch oder gab es da auch Überraschungen?

MN: Also, das Prinzip, die Ergebnisse oder die Art der Berechnung scheint mir sehr logisch und nachvollziehbar. Im Detail müsste man dann jetzt aber nochmal gucken. Es gibt eben Bereiche, wo so ein Flickenteppich ist, wie zum Beispiel gerade hier dieser Farbenbereich Altona-Altstadt, -Nord und Sternschanze, wo sehr viele unterschiedliche Farben durch die Statistischen Gebiete herausgekommen sind. Da würde ich zumindestens im Detail nochmal nachgucken wollen, warum ist es so unterschiedlich. Also die Logik springt mir nicht so in dem Moment entgegen.

AS: Und hinsichtlich der Faktoren, die untersucht wurden, was ja sozialdemographische Faktoren waren, gibt es da weitere Faktoren, von denen, die jetzt betrachtet wurden, die man untersuchen sollte?

MN: Also, es wurden ja jetzt untersucht hauptsächlich so die strukturellen, also wie viele Quadratfläche Nutzung bewohnt ein Mensch, in Bezug auf Baudichte, Baugrund und so weiter, das ist alles sehr logisch und auch absolut sinnvoll. Die Sozialdaten fand ich auch sehr nachvollziehbar, wenn gleich da auch so überraschende Ergebnisse herausgekommen sind, wie die von Relation mit Beschäftigung und Sozial... wie war das?

AS: Sozialversicherungspflichtig beschäftigt und Arbeitslosengeldempfänger.

MN: Genau. Was ich noch interessant fände, welche Faktoren, das ist das, da sprachen wir eben auch schonmal kurz drüber, über die Art des Stromes zum Beispiel. Das erscheint mir ein ganz wichtiger Punkt, auch in Bezug auf Überzeugungsarbeit, Kommunikation mit den Endnutzern, dass das in den Berechnungen scheinbar bislang aufgrund von fehlenden Daten gar keine Rolle spielen kann. Das erscheint mir eine Lücke, wo man zukünftig dran arbeiten sollte.

AS: Gar nicht hinsichtlich der Korrelation, also nicht hinsichtlich der Zusammenhänge, sondern einfach für die Datenlage, um die Auswertung zu erstellen.

MN: Genau. Also jetzt, um ganz allgemein zu wissen, in welchen Gebieten der Anteil der Ökostrombezieher, wo er besonders hoch, wo er besonders niedrig ist. Das scheint mir auch nochmal ein ganz wichtiger Informationsgeber zu sein.

More details on energy sources are needed for a calculation of emissions in every area.

AS: Die bestehenden Korrelationen, die jetzt berechnet wurden, sind die interessant für Maßnahmen, die man entweder einführen möchte, oder bestehende Maßnahmen, dass man die korrigieren möchte? Also für die Schwerpunktsetzung. Ist es da zum Beispiel relevant, dass es eine Korrelation mit zum Beispiel den sozialversicherungspflichtig Beschäftigten gibt, oder mit dem Einkommen oder mit der Wohnfläche?

MN: Das ist interessant. Also was mir noch eingefallen ist, eine Korrelation, die bestimmt auch noch sehr ergebnistauglich wäre, wäre das Thema Mobilität. Weil das glaube ich im hohen Maße auch mit der Dichtefrage und der Entfernung zu den zentraleren Bereichen zusammenhängt und ja eben auch größere Auswirkungen auf die CO_2-Bilanz damit verbunden ist. Das musste jetzt wahrscheinlich im Rahmen der Arbeit aufgrund der notwendigen Eingrenzung ausgelassen werden. Aber auch das könnte man sich gut vorstellen, dass das dann nochmal ganz andere Ergebnisse oder nochmal eine Schärfung der Ergebnisse bringen kann. Und jetzt in Bezug auf Maßnahmen ist es auf jeden Fall... bestätigt die Ergebnisse eigentlich, dass insbesondere der Bereich, mit dem wir hier im Fachamt der Stadt- und Landschaftsplanung zu tun haben, nämlich

The topic of mobility would probably increase trends of lower emissions per capita in dense areas.

die Frage die Struktur der Stadt einfach auch ein ganz wichtiger Punkt ist auch oder gerade auch in Bezug auf das Thema Klima/Klimaschutz. Und dass das Prinzip, das Hamburg als wachsende Stadt seit Jahren verfolgt, nämlich eine Verdichtung der Stadt, dass das eigentlich richtig ist. Dass es auch förderlich ist für das Thema Klimaschutz und man fühlt sich sozusagen bestätigt, dass die Innenentwicklung in der Stadt, zu verdichten gegenüber dem neuen Bauen auf dem noch unberührten Land, Stichwort "Grün Wiese", dass das strukturell absolut richtig ist.

AS: Weil es eben diese Korrelationen mit der Bevölkerungs- und Haushaltsdichte gibt.

MN: Ja, genau.

AS: Zu dem Ansatz selbst: Hältst du die Ebene der Statistischen Gebiete als sinnvoll?

The results approve the current approach, which focuses on the development of the inner city.

MN: Ja, also die Statistischen Gebiete liegen ja zwischen den Stadtteilen, wo man Daten ja relativ einfach besorgen kann, und zwischen den dann aus Datenschutz-Gründen sehr viel individueller oder schwieriger von den Blockbezogenen Daten, also Einzelhaus-bezogene Daten sind ja das aller schwierigste. Die nächste Korrelation ist Blockdaten und die Statistischen Gebiete liegen halt dazwischen. Und eben dadurch ein sehr viel differenzierteren Einblick als die reinen Statistik-Daten. An die Blockdaten kommt man sowieso nicht so ran, das würde einen unangemessen hohen Arbeitsaufwand bedeuten. Insofern ist die Betrachtung der statistischen Gebietseinheiten sehr sinnvoll.

AS: Dann haben wir uns eben angeguckt die Darstellung der Verbräuche und Emissionen resultierend aus Strom und Heizenergie. Das war geographisch dargestellt. Findest du so eine Darstellung sinnvoll, zum Beispiel um konkrete Ziele zu erreichen oder Anreize für lokale Maßnahmen zu schaffen?

MN: Sinnvoll ist das insofern, weil das uns auch hilft, Gebiete ausfindig zu machen, wo man genauer hingucken müsste. Zum Beispiel auch mit dem Ziel, da sind wir ja gerade im Moment auch sehr dabei, herauszufinden, wo würde es Sinn machen, energetische Quartierskonzepte zu starten. Also einen kleineren Teil, der trotzdem quasi so ein Quartier umfassen sollte, zu schauen, wo macht das Sinn? Und da ist die Erhebung hier auf jeden Fall sinnvoll, müsste aber nochmal zusammengebracht werden zum Beispiel mit solchen Fragestellungen, wo sind welche Energienetze vorhanden, um dann in der Zusammenschau zu gucken, an welche Gebiete sollte man prioritär herangehen.

Structures of ownership are highly important to decide where to intervene.

Wichtig sind da auch im Übrigen sehr stark die Eigentumsstrukturen, also die müsste man dann dafür dann auch nochmal drunter legen. Weil da unser Ziel ist eigentlich, mit Gebieten weiterzugehen, wo wir einen größeren Anteil von einem gleichen Eigentümer haben, dass man es nicht mit ganz vielen Streueigentümern zu tun hat, weil dann ist der Erfolg sehr... dann ist es sehr schwierig, damit zu arbeiten. Aber wenn man in einem Gebiet mehrere größere Wohnungsbaugesellschaften zum Beispiel hat, mit denen kann man sehr gut zusammenarbeiten. Dann kann man auch so ein paar Einzeleigentümer mitziehen. Aber von daher wäre das jetzt für uns ein wichtiger Punkt, die Ergebnisse hier zusammen nochmal zu überlagern und dann zu gucken, wo sind primäre Handlungsfelder.

AS: Und ist dir ein vergleichbares Monitoring oder so eine vergleichbare Aufzeichnung bekannt, dass eben wirklich geguckt wird: An welchen Stellen haben wir große Verbräuche?

MN: Also mir persönlich ist es nicht bekannt, aus meinem Handlungsfeld heraus. Aber ich kann mir gut vorstellen, dass es an der BUE derartige Monitorings gibt. Aber ich persönlich kenne sie nicht.

AS: Siehst du ein Problem darin, diese geographische Darstellung der Öffentlichkeit zur Verfügung zu stellen?

MN: Generell bei statistischen Daten hat man ja immer sehr viel Interpretationsspielraum und es gibt auch Einflüsse, die... oder anders formuliert muss ich sagen: Wenn die Daten sehr sauber sind und sie sind wirklich gut erklärbar, dann habe ich den Eindruck, dass das ein gutes Instrument ist, mit dem man auch an die Öffentlichkeit gehen kann. Ich bin mir nur nicht sicher, ob wir in Hamburg schon da wirklich so weit sind, dass die Datenlage schon so sauber ist, um das auch wirklich zu machen. Weil es eröffnet natürlich auch die Gefahr, dass man viele einzelne Ecken lange diskutiert und dann am Ende trotzdem offen ist, woher kommen jetzt Unterschiede. Also wenn die Transparenz und die Klarheit, wo die Daten herkommen, noch nicht sauber genug ist, eröffnet man da einfach sehr große Diskussionsräume. Und die vielleicht in der Öffentlichkeit sinnvoller ohne solche Quantitäten, sondern eher auf einer qualitativen Ebene zu führen wäre. Also es ist eine Chance, aber auch eine Gefahr, womit man sehr sensibel umgehen muss.

When results are published it is necessary to have very ‘clean’ data.

AS: Hältst du es für sinnvoll gerade auch auf Bezirksebene konkrete Einsparziele zu formulieren, wie wir es jetzt zum Beispiel auf Hamburger Ebene gesehen haben?

MN: Inwieweit es Sinn macht, neben der Hamburger Bilanz jetzt auch noch für Altona eigene, noch dazu andere Ziele zu formulieren, da würde ich eigentlich sagen nein, das macht keinen Sinn. Da sollte Altona oder die Bezirke sich der Hamburgischen Grundzielrichtung vollkommen anschließen und vielmehr gucken, wie im Bezirk die Ziele denn konkret umgesetzt werden können. Und das tun wir ja jetzt auch durch das Klimaschutzkonzept, indem wir dort Maßnahmen zusammensammeln als Ergebnis von vielen, vielen Gesprächen, die wir geführt haben, mit Experten, mit Bürgern, mit Verwaltung, mit Fachbehörden und so weiter. Um da zu gucken, dass wir da sinnvolle und vor allem umsetzbare Maßnahmen herauskristallisieren, wo man

The focus of the municipality is rather directed to measures than to defining goals.

sich in dem nächsten Jahr verstärkt kümmern möchte. Also eher die Umsetzung als denn die Zielebene.

AS: Und da nochmal nachgehakt: Wäre es denn dann aber denkbar, einfach genau das gleiche Ziel zu übernehmen, auch in das Klimaschutzkonzept, und sozusagen zu propagieren "Altona erfüllt die Hamburger Ziele"? Also trotzdem mehr zielorientiert zu arbeiten sozusagen?

MN: Ja, also Übernehmen des Hamburger Zieles absolut. Aber man kann im Grunde nur sagen, dass Altona sich das Ziel gesetzt hat, die Ziele auch wirklich zu erfüllen und im Idealfall sogar auch noch überzuerfüllen.

AS: Und gibt es dann Möglichkeiten in Altona, das auch nachzuverfolgen, auf welchem Stand man ist, um diese Ziele zu erfüllen?

Ways to monitor emissions at the municipal level are not quite clear yet.

MN: Ja, das ist ein heikles Thema, was mir selber auch noch gar nicht so wirklich klar ist. Wir sind ja aufgerufen, im Rahmen des Klimaschutzkonzeptes auch nachher ein Controlling/Monitoring durchzuführen. Wie das im Einzelnen ablaufen wird, das ist mir persönlich noch nicht klar, weil wir hier im Bezirk eben auch gar nicht die Möglichkeit haben, Daten zu erfassen, wie das wahrscheinlich die Fachbehörde kann. Da würde ich auch denken, das ist für uns wichtig, dass wir diese Aufgabe... dass wir uns überhaupt an die Systematik der BUE halten werden, also nicht irgendwie andere, weil es gibt ja unterschiedlichste Berechnungsmethoden. Und für uns wäre es wichtig, dass wir die hamburgweite auch anwenden. Aber wahrscheinlich auch nur festmachen dann an bestimmten, auch wirklich erfassbaren Daten. Also nur da, wo wirklich Daten zur Verfügung stehen, und das ist eben Strom, Gasverbrauch, und dann hört es aber auch schon wieder auf. Nur anhand dessen können wir uns selber vornehmen, dann auch selbst zu monitoren. Aber letztendlich ist diese Monitoring-Aufgabe so ein eigenständiges, großes Feld, dass wir da dies wirklich nur bis zu einem machbaren Umfang machen können und uns lieber darauf konzentrieren, Maßnahmen umzusetzen und voranzubringen.

AS: Dann kommen wir zur letzten Frage, und das geht nochmal in eine ganz andere Richtung. Und zwar die Einheit der Verbrauchsdaten. Wir haben jetzt verschiedene Daten gesehen und es gibt verschiedene Möglichkeiten, die darzustellen. Also zum Beispiel Energieverbrauch pro Quadratmeter, pro Einwohner, oder die daraus resultierenden Treibhausgasemissionen, auch wieder pro Quadratmeter und pro Einwohner. Gibt es von deiner Seite eine bevorzugte Variante, in welcher Einheit man arbeitet?

MN: Wir sprachen eben schonmal darüber, dass es ja letztendlich eigentlich um die Treibhausgas-Einsparung gehen müsste. Insofern ist die THG-Emission eigentlich das Ideal. Nur liegen da zum Teil die Daten überhaupt nicht vor. Wir sprachen darüber, dass auch die Art des Stromes bislang noch gar nicht in die Verbrauchsdaten zum Beispiel von Netz Hamburg einfließt, und das finde ich außerordentlich schade. Aber aus pragmatischen Gründen würde ich jetzt sagen, die Verbrauchsdaten sind das, was real im Moment vorhanden ist. Deswegen würde ich denen im Moment die Priorität geben, würde mir aber sehr wünschen, dass die Daten so differenziert erfasst werden, dass wir irgendwann auch wirklich ein THG-Bilanz oder Emissionsdaten, dass wir damit arbeiten. Weil die letztendlich eigentlich zu dem Ziel führen, was für uns wichtig ist. Nur wenn die Daten nicht da sind, kann man sie ja auch nicht anwenden.

Due to the currently insufficient availability of emission factors, the use of energy data might be better than the use of emission data.

AS: Und dann bevorzugter Weise pro Quadratmeter oder pro Einwohner angegeben?

MN: Pro Einwohner. Dadurch dass wir in Hamburg wachsende Stadt sind, halte ich die Bezugsgröße auf den Einwohner bezogen für eine ganz wichtige, weil ansonsten da im Grunde zwei Themen miteinander vermischt werden. Die absoluten Zahlen auch pro Fläche sind meines Erachtens nicht so aussagekräftig wie der pro Einwohner. Letztlich haben wir das vorgegebene Ziel oder das Ist-Zustand ist so, dass wir wachsen. Das kann man nicht in Frage stellen. Insofern muss unser Ziel sein, die Verbräuche pro Einwohner zu reduzieren. Bezogen auf die Fläche werden wir es überhaupt nicht schaffen. Das ist sozusagen eine nicht mögliche Forderung.

Energy use and emissions per capita are the preferred unit.

AS: Alles klar. Dann vielen Dank, dass du meine Fragen beantwortet hast.

MN: Sehr gerne.

Appendix P

Transcript of the Interview with Dipl.-Ing. Jan Gerbitz

Time: 10.08.2018 at 10.00 am

Place: ZEBAU office in Hamburg (Große Elbstraße 146)

Language: German

Interview partner: Since 2002 Jan Gerbitz is Project Manager at ZEBAU GmbH. He has also gathered experience as Project Coordinator at IBA Hamburg GmbH and is currently working on the climate protection concept for Altona.

Annika Stein (AS): Erst einmal nochmal ganz vielen Dank, dass du dir die Zeit nimmst.

Jan Gerbitz (JG): Gerne.

AS: Dann fangen wir doch direkt an, wo wir gerade schon darüber gesprochen haben, mit dem Thema: Ihr sitzt ja am Klimaschutzkonzept für Altona. Und du hast gerade angefangen zu erzählen, was ihr eigentlich mit den Verbrauchsdaten macht.

In the climate protection concept, areas with high heat energy use are identified. If they are not connected to a district heat grid yet, this could be a step in the future

JG: Genau. Ja, unsere Herangehensweise ist die, dass wir die vorhandenen Verbrauchsdaten, die wir von den Netzbetreibern bekommen haben, sowohl für Strom als auch für den Gasverbrauch, analysiert haben und aus den Verbrauchswerten für den Gasverbrauch eine Heat-Map erstellt haben, um die Schwerpunkte des Wärmeverbrauchs darstellen zu können. Und diese Heat-Map haben wir dann verschnitten mit einer Karte der bestehenden Netzgebiete für die Fernwärme als auch für die einzelnen Nahwärmegebiete. Wobei sozusagen Hansewerk Natur und das Verbundnetz West ja schon auch ein relativ großes Fernwärmegebiet ist, weil das ja mehrere Nahwärmenetze miteinander verbunden hat. Und Ziel ist eben, dass wir die Gebiete herauskristallisieren wollten, die einen hohen Wärmeverbrauch haben, aber im Moment noch nicht durch Nahwärme oder Fernwärme erschlossen sind, um auf der Grundlage zu gucken, wo die Entwicklung von Nahwärmenetzen interessant oder sinnvoll sein könnte. Und diese dann eben natürlich möglichst mit Projekten der energetischen Quartierssanierung auch zu bearbeiten.

AS: Ich habe ja vorhin erzählt, ich hatte gerade ein Telefonat mit der Frau Teunis vom Statistikamt Nord. Und da ging es um CO_2-Emissionsfaktoren. Mir ist nämlich aufgefallen, dass der von denen berechnete Fernwärmefaktor für Hamburg, also nicht Altona speziell, sondern ganz Hamburg, höher ist als der CO_2-Emissionsfaktor für Gas.

JG: Das ist auch verständlich, weil auch sehr viel Kohle in das Vattenfall-Netzwerk reingeht.

AS: Weil du ja gerade meintest, ihr schaut: An welchen Stellen sind Gebiete noch nicht von der Fernwärme erschlossen und wo sind Potenziale? Wie bringst du das zusammen?

JG: Das ist nicht ganz korrekt. Die nicht durch leitungsgebundene Wärmeversorgung erschlossen sind, also ich meine sozusagen Fernwärme und Nahwärme. Wir haben zum einen die Möglichkeit natürlich, an das Fernwärmenetz dann noch anzuschließen. Aber natürlich eine andere Möglichkeit, die jetzt auf jeden Fall kurzfristig natürlich die bessere wäre, dann dort Nahwärme-Inseln, meinetwegen auch mit Vattenfall, aber natürlich eher mit anderen Anbietern, das heißt mit Hamburg Energie und mit Urbana oder vielleicht enercity, dann entwickeln würde, weil die eben durch ihre Wärmekonzepte natürlich sehr viel bessere CO_2-Emissionsfaktoren vorweisen könnten. Weil die mindestens auf jeden Fall mit Erdgas-BHKWs arbeiten, aber natürlich auch immer wieder versuchen, auch erneuerbare Energien wie Solarthermie oder eben auch innovative Techniken wie Power to Heat dann auch mit einzubinden.

Currently, Vattenfall's district heat has a very high emission factor, because it uses coal as energy source. Local heating grids are better, since they use gas or renewable energy sources.

Das heißt, sind wir da im Moment Anbieter- und Technologie-offen, aber natürlich Grundvoraussetzung, um eben einen Anschluss an das große Fernwärmenetz von Vattenfall Wärme Hamburg empfehlen zu können, wobei man natürlich davon ausgehen sollte und ausgehen muss, dass die Fernwärme sich in den nächsten Jahren ändern wird. Das heißt, dass dann eben wirklich Wedel ersetzt wird, dass Tiefstack auf einen Gas-GUD umgewandelt wird, und dass eben das Gesamtkonzept auch nach und nach umgesetzt wird. Das heißt, was eben gerade im Süderelbe-Raum mit der Abwärmenutzung des Stahlwerkes, des Aluminiumwerkes, der Großwärmepumpe, des Aquifär-Speichers, oder alles was dort geplant ist, dass es dann auch nach und nach umgesetzt wird, damit eben überhaupt die Fernwärme zukunftsfähig wird. Und überhaupt eine realistische Option ist.

Wir haben natürlich gerade in Altona das Zentrum für Resourcen und Energie von der Stadtreinigung. Das heißt, dort wird dann ganz lokal dafür gesorgt, dass die Fernwärme dann auch verbessert wird. Aber das ist natürlich in gewisser Weise auch nur ein kleiner Baustein, der im Moment gerade feststeht. Die anderen Bausteine sind dann ja noch in der Diskussion.

The use of waste heat is a great potential.

Genau, deshalb geht es uns erstmal darum, Gebiete zu identifizieren, die so eine hohe Wärmedichte haben, dass sich dort eine netzgebundene Lösung, also eine Nahwärme-/Fernwärme-Lösung anbietet. Weil für Gebiete mit einer geringeren Energiedichte sich das da normalerweise wirtschaftlich nicht darstellen lässt und man deshalb dort natürlich eher Einzellösung anstreben sollte. Also basiert auf Solarthermie, Photovoltaik, Wärmepumpen, meinetwegen auch noch effizientere Gastechnologien, die natürlich auch noch besser sind als konventionelle Gaskessel und Ähnliches.

AS: Das heißt, für euch sind wichtiger die absoluten Werte des Wärmeverbrauchs als die Berechnung pro Kopf oder pro Quadratmeter?

To decide where to intervene, it is important to know energy use per ground area.
It is less important to know how efficient buildings or people are.

JG: Es ist natürlich interessant, dass man das schon in Verbindung bringen kann. Da interessieren uns wirklich die Wärmeverbräuche pro Bruttogrundstücksfläche. Und eigentlich mehr oder weniger, ob diese dann durch eine große Baumasse, die aber effizient ist, zustande kommen oder durch eine relativ geringe Baumasse mit aber einem hohen Energieverbrauch, ist im ersten Blick eigentlich egal. Das wird dann später interessant, wenn man dann wirklich zu solchen Auslegungsfragen und dann auch zur Berechnung von Wärmepreisen kommt. Weil die natürlich immer zusammenhängen, aus dem Grundpreis mit dem Arbeitspreis. Wenn man dort natürlich viele Nutzer hat mit relativ geringem Wärmebedarf, dann haben die natürlich einen relativ hohen Grundpreis und relativ wenig Arbeitspreis zu bezahlen und dadurch wird natürlich der durchschnittliche Wärmepreis dann relativ hoch. Aber das ist natürlich in Neubaugebieten noch vertretbar, weil die insgesamt gesehen geringe Energiekosten durch einen geringen Verbrauch haben. Da muss man dann auch aufpassen, dass man nicht Äpfel mit Birnen vergleicht. Dann kann in einem Neubaugebiet auch mal ein Wärmepreis von 10 Cent vertretbar sein, während natürlich in einem Bestandsgebiet, das unsaniert ist und nicht saniert werden kann, natürlich 10 Cent sehr hoch sind.

The influence of the structure of inhabitants and their behaviour has already been looked at in the past.

Trotzdem, sozusagen diese Fragestellung, ob der Wärmeverbrauch eines Gebietes weniger mit den Gebäuden zusammenhängt, sondern eher mehr dann auch mit den dort lebenden Menschen, das war ja schon eine Fragestellung, die im Rahmen der IBA Hamburg aufgeworfen wurde. Im Rahmen von EnEV-Stadt IBA Hamburg, also dem EnEV-Wärme, beziehungsweise EnEV-Stadt-Projektes, und da hatte sich ja auch schon Frau Dr. Peters damit beschäftigt, ob man dort Korrelationen herstellen kann. Und das wäre schon nochmal eine andere Herangehensweise, weil man ja ansonsten jetzt eher auf die Baujahre geachtet hat, die aber durch die unterschiedlichen Sanierungsstandards und natürlich auch durch unterschiedliche Nutzungen gar nicht so signifikant sind wie die Gebäudenutzung oder wirklich der Gebäudezustand. Deshalb war das so der Knackpunkt, wo wir auch gesagt haben, allein aus den Baujahren kann man dann eigentlich keine Energiebedarfe ablesen.

AS: Genau, und dann auch nochmal der Unterschied zwischen den Energiebedarfen und den tatsächlichen Verbräuchen, wo dann eben die Bewohnerstrukturen mit einfließen. Das heißt, könntest du dir vorstellen, wenn man jetzt eine Erkenntnis über bestehende Korrelationen hat oder auch die, die ich zum Beispiel ausgerechnet habe, dass das einerseits dazu führen kann, den Energieverbrauch besser einzuschätzen, aber vielleicht sogar auch in Maßnahmen münden kann? Oder ist das zu weit gegriffen?

JG: Ich kann mir die Maßnahmen im Moment noch nicht vorstellen. Also, was ich schon denke, das wäre nochmal eigentlich eine Fragestellung, ob eben die Korrelationen signifikant sind, oder ob sie sich nur aus vorherigen Korrelationen ergeben. Man kann natürlich vieles aus dem Haushaltseinkommen ablesen. Also natürlich hat jemand mit einem hohen Haushaltseinkommen eher ein Einfamilienhaus, hat dadurch mehr Wohnfläche pro Person, hat natürlich dadurch mehr Fläche, dadurch einen höheren Heizwärmeverbrauch, hat mehr elektrische Geräte, ist auch mit mehr elektrischen Geräten ausgestattet, dann kommt vielleicht die Sauna oder der Swimmingpool nochmal dazu oder Ähnliches. Das hat dann Auswirkungen auf Bautypologien und auf sozusagen Anzahl der Haushalte pro Hektar Fläche und auch auf die Geschossigkeit, das heißt, da ist eigentlich so eine ganze Reihe von Abhängigkeiten drin. Für mich wäre jetzt eigentlich interessant, ob es dort Zusammenhänge gibt, die dem so ein kleines bisschen entgegenstehen. Da hatte ich ja schon erwähnt mit den Senioren, weil da auch schon die Frage war während der IBA-Zeit, ob Senioren ganz einfach einen anderen Wärmebedarf haben als sozusagen der Durchschnitts-Mensch. Weil sie gegebenenfalls öfter und dauerhaft zu Hause sind, weil sie ein anderes Kälte- und Wärmeempfinden haben und deshalb eine höhere Heiztemperatur haben. Und das könnten natürlich interessante Zahlen sein, die sich dann natürlich auswirken auf den Wärmebedarf. Und das kann natürlich unabhängig sein vom Haushaltseinkommen, obwohl natürlich der Durchschnitts-Rentner natürlich eigentlich weniger Geld zur Verfügung hat als der Durchschnitts-Arbeitnehmer. Was wir uns eben auch gefragt haben, ob auch die Empfänger von Sozialleistungen auch einen höheren Energieverbrauch haben, zum einen weil sie gegebenenfalls die Energiekosten nicht selber tragen müssen, aber auch weil sie gegebenenfalls mehr zu Hause sind, und vielleicht dann auch einen höheren Stromverbrauch haben, weil sie Medien mehr nutzen. Also das wären so Punkte, die man dann schon bei einer Simulation oder einer Prognose für den Energieverbrauch von einzelnen Gebäuden berücksichtigen sollte. Wenn eben so das typische Nutzerprofil eindeutig ganz einfach nicht zutrifft.

High income probably influences a lot of other factors, such as area per inhabitant, electrical devices, building type and density.

AS: Genau, also das was ich berechnet habe, da kam heraus, dass der Anteil unter den Bewohnern an Menschen, die Arbeitslosengeld empfangen, dass der dazu führt, dass der Energieverbrauch, sowohl Strom als auch Heizenergie, sinkt. Also auf der Ebene der Statistischen Gebiete. Und anders bei dem Anteil der Haushalte mit über 65-Jährigen, das hat nur bedingt zu einem höheren Heizverbrauch geführt. Allerdings muss man natürlich immer im Kopf behalten, auf dieser Ebene der Statistischen Gebiete. Weil für mich ja die Fragestellung ist: Lässt sich auf dieser Ebene arbeiten und auch dort Korrelationen feststellen? Weil das, was du zum Beispiel eben gerade über Senioren oder ältere Bewohner gesagt hast, das sind ja nachgewiesene Einflüsse oder Bedürfnisse, dass je älter man wird, umso wärmer hat man es gerne im Raum. Von daher ist das auf der individuellen Ebene auf jeden Fall wahr. Und für mich war ja die Frage, ist das auch auf der Statistischen Gebiets-Ebene wahr. Deswegen vielleicht dazu nochmal die Frage: Findest du, dass das eine sinnvolle Ebene ist, auf der man sich bewegt?

The level of Statistical Areas can serve as a first indicator. However, to decide on specific climate action, the level is probably still too high.

JG: Die Frage ist ja, welche Planung oder welche Maßnahmen man auf der Ebene des Statistischen Gebietes anstellt. Sozusagen ab welcher Detail-Tiefe bei einer Konzept-Erstellung oder Maßnahmen-Entwicklung man sich auf Quartiersebene dann eher begeben muss. Da habe ich schon das Gefühl, dass diese Abhängigkeiten oder diese Unterschiede noch zu gering sind, um auf dieser grobmaschigen Ebene Entscheidungen zu treffen. Auf dieser grobmaschigen Ebene würde man ja so grundsätzliche Entscheidungen treffen wie: Es könnte grundsätzlich ein nahwärmeversorgtes Gebiet zum Beispiel sein. Da glaube ich, dass die Statistischen Gebiete zu grob sind, um solche Entscheidungen treffen zu können.

Also jetzt auch in Altona, wo wir mit der Quartiersbetrachtung schon auch nochmal detaillierter sind und diese Potential-Gebiete schon detaillierter sind als Statistische Gebiete. Ich glaube, in einer gewissen Flughöhe für eine sehr grobe Einschätzung sind Statistische Gebiete noch ausreichend, aber da ist dann die Frage: Sind die Unterschiede, die du herausgearbeitet hast, so signifikant, dass man da auf der Grundlage Entscheidungen trifft? Oder ist es sozusagen nur ein Teil? Also normalerweise würde man, wenn man jetzt auf diese Karte drauf guckt, würde man eher auf Bautypologien gucken. Also eigentlich würde ich mir jetzt einen Schwarzplan vornehmen, oder einen Plan mit Geschossigkeiten, und dann sagen: Okay, Einfamilienhaus-Gebiet fliegt raus. Das kann man schon eindeutig sehen. Dann haben wir irgendwie eindeutig Bestandsgebiet, das ist interessant. Da haben wir irgendwie eine Hochhaus-Siedlung, das ist auch interessant. Und mehrgeschossiger Wohnungsbau, der dann auch neuer sein kann, da muss man sich das dann noch ein bisschen genauer angucken.

AS: Das wäre ja sogar ein Verfahren, das man so durchführen könnte. Man könnte ja praktisch diese GIS-Daten einlesen, dann eben die darüber legen, zum Beispiel Geschossigkeit und Typologie, und dann Kriterien formulieren und dann automatisch so ein Ranking durchführen. Also jedes Gebiet sammelt einen Punkt in den jeweiligen Kategorien, sodass man dann am Ende seine Kerngebiete herausgearbeitet hat, wo man den Fokus drauf setzen möchte.

JG: Ja. Für eine Grob-Analyse ist das auf jeden Fall sinnvoll. Ich gucke mir dann ja schon einfach den Schwarzplan an und habe dann ja schon Gebiete im Blick, die man sich dann weiter angucken sollte, und welche, die dann mehr oder weniger rausfliegen. Das bestätigt sich dann auch, wenn man dann in die weitere Analyse geht. Es ist nur dann die Frage, ob es immer so 100%-ig zutrifft, oder welche Aspekte dann dazu führen, dass Gebiete dann doch wieder rausfliegen. Natürlich so etwas wie Vollmodernisierung, ist dann natürlich so ein Aspekt. Aber den kann man dann natürlich nicht aus dem Schwarzplan herauslesen.

AS: Eine weitere Frage von mir ist auch, ob du es für sinnvoll hältst, dass so geographisch darzustellen. Ich gehe mal davon aus, dadurch dass ihr das ähnlich angeht, dass das als Einschätzung auch für euch auf jeden Fall sinnvoll ist. Aber dann noch weiterführend: Siehst du Probleme darin, diese geographische Darstellung auch der Öffentlichkeit zur Verfügung zu stellen oder das vielleicht sogar zu nutzen gegenüber der Öffentlichkeit?

JG: Für sozusagen interne Gespräche ist es natürlich schon interessant und wertvoll. Die Frage ist, ob man dadurch gewisse Bevölkerungsschichten dann stigmatisiert oder dann eher Abwehr-Reaktionen erzeugt. Also fühlen sich sozusagen die Bewohner von Blankenese angegriffen, weil man denen einen Spiegel vorhält, dass sie natürlich aufgrund ihrer luxeriösen Lebensverhältnisse natürlich einen höheren Energieverbrauch haben und dann natürlich verstärkt wahrscheinlich zum Klimawandel beitragen. Außer sie tun sehr aktiv etwas dagegen. Also kümmern sich dann irgendwie um Modernisierungen und Solarthermie und was auch immer. Also widmen sich dem Thema. Es kann zum Aufrütteln dienen, kann aber natürlich auch Gegenwehr hervorrufen. Deshalb ist das glaube ich so ein bisschen mit Vorsicht zu genießen.

Geographical visualizations are very useful for internal conversations. In public however they could lead to a stigmatisation of certain population groups.

AS: Hältst du es generell für sinnvoll, dass auf Bezirksebene konkrete Klimaziele formuliert werden, also auch quantifiziert werden?

JG: Ich glaube, die Schwierigkeit ist, dass sich allein schon der CO_2-Verbrauch auf Bezirksebene schwierig zu berechnen ist. Thema Mobilitätsdaten: sind immer sehr schwierig, sind immer auf städtischer Ebene zu erhalten. Man müsste ansonsten den Modul-Split umrechnen, da wird Helmut Adwiraah [von Averdung Ingenieursgesallschaft mbH] demnächst noch etwas zu tun haben. Da hat aber auch die Leitstelle Klimaschutz gesagt, wir sollen sonst einfach die Hamburger Werte nehmen, und dann auf Bezirksebene runterbrechen. Was ich eigentlich sehr unbefriedigend finde. Altona ist nun ein sehr durchmischtes Gebiet, wo dann vielleicht so ein Durchschnitt sinnvoll ist, aber in anderen Quartieren, die entweder noch viel ländlicher geprägt sind, wie zum Beispiel Bergedorf, da ist der Modul-Split auf jeden Fall anders, und entsprechend dann auch der CO_2-Ausstoß. Und in verdichteten Gebieten wie Eimsbüttel wird es zur anderen Seite sein.

AS: Und in Bezug auf Wohngebäude?

JG: Finde ich es eigentlich nicht sinnvoll, weil sich die Gebäudesubstanz nicht signifikant unterscheidet von denen in anderen Bezirken. Und ich denke schon, dass man die Hamburger Ziele nachvollziehen sollte und denen auch nachgehen soll. Und viele Akteure sind ja auch nicht nur im Bezirk aktiv. Also wenn ich an die

Wohnungsbaugenossenschaften denke, zum Beispiel SAGA, die werden ja nicht einen Gebäudestandard für Altona und einen für Eimsbüttel einführen. Sondern das sind dann eher grundsätzliche, hamburgweite Entscheidungen. Nein, deshalb sind es vielleicht eher Einzelziele, die man dann mit Einzelakteuren verabredet.

AS: Das heißt ja, dass zum Beispiel das Hamburger Ziel von der Begrenzung des Energieverbrauchs pro Quadratmeter Wohnfläche, immer nur hamburgweit bilanziert wird, richtig?

JG: Ja, also eigentlich, das hattest du ja auch schon gesagt, diese Werte liegen ja nicht vor, sondern es liegen ja eher Teilzahlen vor. Also zum Beispiel hat der VNG [VNG AG] zum Beispiel den durchschnittlichen Energieverbrauch errechnet. Dann gibt es natürlich die Daten der Ableseunternehmen, also ista [ista Deutschland GmbH]. Die haben ja sozusagen einen Wärmeatlas für ganz Deutschland erstellt. Und die SAGA macht da ja auch eigene Untersuchungen. Aber das ist dann ja auch jeweils nur ein Teilbereich. Gerade die ganzen Wohnungseigentümer-Gemeinschaften oder auch die Besitzer von kleineren, mehrgeschossigen Wohnungsbauten, sind natürlich auch die, die dem Trend hinterherhinken. Weil die zum Teil weniger investieren als die institutionellen Wohnungsbauunternehmen. Deshalb kann man sich da natürlich auch sehr in die Tasche lügen.

Hamburg's energy goals are very ambitious.

Also mir ist jetzt nicht bewusst, dass es wirklich eine Gesamt-Erhebung für ganz Hamburg gibt, aus der man ablesen kann, ob die Ziele wirklich auch erreicht werden. Mal ganz abgesehen davon, dass ich diese Ziele auch sehr ambitioniert finde und mir nicht bewusst ist, dass irgendjemand das mal nachgewiesen hat, dass diese überhaupt erreichbar sind. Weil wir natürlich schon Rahmenbedingungen haben, die das Ganze dann auch verhindern. Wenn man allein schon die ganzen denkmalgeschützten Gebäude oder allein schon die mit erhaltenswertem Fassadenbild und ähnlichem mit reinrechnet, dann landet man eben nicht bei diesem Wert. Und im Gegenzug müssten natürlich alle anderen Gebäude sehr viel bessere Werte erreichen, die auf jeden Fall in der Sanierung nicht zu erreichen sind und wo auch im Neubau schon die Grenzen auf jeden Fall erreicht sind. Also da gibt es auch die Diskussion in der BUE, dass der bisher abgestimmte zukünftige Standard Effizienzhaus 55 sein soll. Das macht ja jetzt auch die SAGA. Dass man eben anstrebt, Gebäude als Effizienzhaus 55 zu realisieren. Wenn man sich das aber konkret anguckt, ist das dann vielleicht so gerade eben dieser Zielwert. Und eigentlich müsste man im Neubau sehr viel besser bauen, um dann den Bestand und gerade die historischen Gebäude ausgleichen zu können. Deshalb hakt das da schon auf allen Ebenen.

AS: Genau, und für mich immer sehr verwunderlich ist, dass man so ein konkretes Ziel hat, es auch beziffert, und dann aber gar nicht hinsichtlich des Monitorings nachforscht, sondern das erstmal allein dastehen lässt. Und dann zwar Maßnahmen einbringt, die die

Emissionen reduzieren, aber das nie ins Verhältnis bringen kann, oder ist das nur mein Eindruck?

JG: Ja, ich habe auch den Eindruck, das meinte ich ja schon. Der Hamburger Klimaplan ist ja auch eher bottom-up entstanden. Er stammt ja aus dem Klimaschutzkonzept, wo ja irgendwie 300 Einzelmaßnahmen drin waren. Entsprechend ist ja im Moment auch das Monitoring. Dass man eigentlich ein paar übergeordnete Verbrauchszahlen natürlich hat. Dann ist da irgendwie die große Unsicherheit, was die nicht-leitungsgebundenen Wärmeversorgungen anbelangt, also Heizöl und aber eben auch wie viel wird dann über Biomasse und wie viel über Solarthermie zugeheizt. Es gibt dann eben diese Einzelprojekte, die dann von unten zusammengezählt werden.

Da gibt es glaube ich auch im Moment noch eine gewisse Unsicherheit und das Ziel ist ja auch, bis 2020 es bei diesem System zu belassen. Und dass erst das Klimaschutzziel von 2030 wirklich als Gesamtbilanz monitort werden soll. Im Moment ist man ja eher dabei, diese 2 Millionen Tonnen einzeln zusammen zu sammeln. Dafür gibt es ja auch das Monitoring, wo dann jede Dienststelle der Stadt Hamburg einzelne Maßnahmen berichten muss und selber beziffern soll. Sozusagen wie viel CO_2-Einsparung mit reinkommt. Was natürlich auch eine Schwierigkeit macht, weil danach natürlich gegebenenfalls unterschiedliche Konzepte, unterschiedliche Aspekte dann zusammengerechnet werden.

There are a few uncertainties involved in Hamburg's bottom-up approach of CO_2 accounting.

Also da rechnet dann die IFB die Relevanz der Förderung rein, der Einzel-Bauherr rechnet für das eigene Gebäude, obwohl er das über die Förderung gemacht hat. Dann die Wärmeversorgung wird dann gegebenenfalls auch noch mit reingerechnet. Also ist da eine gewisse Unsicherheit drin, ob nicht manche Maßnahme oder manche Reduktionen nicht auch doppelt oder dreifach gezählt werden. Das hatten wir auch im Rahmen der IBA, wo wir dann eben auch unsere Maßnahmen reporten sollten, wo es dann auch darum ging, das eine Gebäude hat die normalen IFB-Förderungen bekommen für den Gebäudestandard, dann haben wir noch eine Sonderförderung für die Eigenfassade gegeben, außerdem hängt es am Energieverbund und wir haben ja noch Veranstaltungen dazu gemacht. Und am Ende hatten wir dann sozusagen fünf Einzel-Maßnahmen, die dann zu einer CO_2-Einsparung geführt haben. Und die Frage war, wo man dann die Abgrenzung wirklich ziehen soll.

AS: Ich glaube, wir haben im Prinzip auch schon das meiste besprochen. Ich würde ganz gerne auf die letzte Frage, die ja so ein bisschen heraussticht, nochmal zu sprechen kommen. Die ist relativ simpel und kurz, aber natürlich trotzdem sehr wichtig: In welcher Einheit würdest du es bevorzugen, klimafreundliches Handeln oder überhaupt klimabeeinflussendes Handeln darzustellen - lieber die Energieverbräuche, also Kilowattstunden, oder die Emissionen, und dann wiederum gefragt, pro Fläche oder pro Einwohner?

JG: Beim Energieverbrauch hat man ja nur die Energie-Einsparungen mit drin. Bei den Treibhausgas-Emissionen dann ja auch nochmal die Wahl des Energieträgers. Deshalb eigentlich aus Klimaschutz-Aspekten müssten es eigentlich die Treibhausgas-Emissionen sein. Das hat natürlich als Nachteil, dass gegebenenfalls gerade die Wärmeversorgung nicht im Einflussbereich des einzelnen Menschen oftmals liegt. Weil welche CO_2-Faktoren die Fernwärme hat oder wie die Wärmeversorgung meines Mietshauses im Keller aussieht, da habe ich keinen Einfluss drauf. Das entbindet einen natürlich ein bisschen aus der Verpflichtung, dass man selber auch Energie einsparen kann. Deshalb hat das schon so einen gewissen Nachteil.

The advantage of energy use as unit is that the responsibility and the ability to act is within the user.

Die andere Frage ist sozusagen: Wen will man motivieren? Will man sagen: Du Einwohner kannst etwas tun. Das ist natürlich gerade beim Stromverbrauch und bei den Treibhausgas-Emissionen ganz relevant. Natürlich kann man irgendwie den eigenen CO_2-Fußabdruck schonmal eindeutig reduzieren, indem ich einfach nur Ökostrom bestelle. Und das wäre natürlich bei Quadratmetern nicht drin und das wäre auch beim Energieverbrauch für Strom noch nicht drin. Obwohl oft natürlich energieeffiziente Geräte der erste Schritt sind, der sich dann natürlich auch im Geldbeutel auswirkt. Was natürlich für manche Leute dann wieder ein Antrieb ist, auch selber etwas zu machen.

Pro Quadratmeter ist immer die Frage, pro Grundfläche oder pro Geschossfläche also sozusagen Wohnfläche. Und wenn man natürlich aus der Stadtplaner-Sicht kommt, wäre wahrscheinlich pro Quadratmeter Grundfläche ganz interessant, weil das eben dann Energie-Dichten oder Hot-Spots der Treibhausgas-Emissionen ausdrückt. Für den Architekten ist es dann wieder interessant, wie es pro Quadratmeter Wohnfläche aussieht, weil es dann ja die Rückschlüsse auf die Energieeffizienz der Gebäudehülle beziehungsweise dann auf die Wärmeversorgung und die gesamte Klimabilanz des Gebäudes zulässt. Deshalb ist glaube ich schon die Frage: Wer ist die Zielgruppe? Und was will man bewirken durch diese Darstellung?

Regarding the individual building, especially the new ones, the share of embodied emissions should not be underestimated.

Ich habe noch einen Punkt. Das war alles jetzt ein bisschen gekürzt. Du hattest geschrieben, dass natürlich beim Energieverbrauch der Schwerpunkt liegt in der Betriebsphase. Das stimmt natürlich sozusagen für die Bestandsgebäude, widerspricht natürlich so ein bisschen dieser Grund-Diskussion, dass man gerade im Neubaubereich auch verstärkt auf den Klimaschutz-Rucksack der Gebäudekonstruktion achten soll. Und natürlich möglichst dann in Richtung nachhaltige und nachwachsende Baustoffe und gegebenenfalls auch Richtung Holzbau gehen sollte. Weil gerade im Neubau schon die Emissionen und der Energieverbrauch der Konstruktion, also der grauen Energien, größer ist, als der Energieverbrauch während der Betriebsphase. Und deshalb ist das in dem Bereich schon relevant. Das ist natürlich auch eine CO_2-

Kennziffer, die ja nicht im Statistischen Gebiet erhoben wird, sondern der Energieverbrauch fällt natürlich zum größten Teil auf der Autobahn an durch den Transport, aber natürlich erst recht an den Produktionsstätten. Also das zählt dann wieder zum Teil zum Sektor Industrie und die Industrie liegt dann natürlich auch außerhalb der Baugebiete. Deshalb ist es eigentlich ein CO_2-Fußabdruck, den man sehr einfach outgesourct hat. Gerade, wenn man sich anguckt, dass die Bauindustrie der größte Resourcen-Verbraucher ist und beim Energieverbrauch irgendwie auf Platz drei liegt, dann ist das natürlich schon ein relevanter Faktor. Aber der natürlich irrelevant ist für das eigene Statistische Gebiet, zumindest so, wie man das erhebt.

AS: Genau, das ist ein guter Hinweis. Und im Prinzip ist das auch die Tendenz, die ich natürlich aufweise. Dass mit einem steigenden Gebäude-Standard auch die graue Energie, die in der Konstruktion steckt, steigt. Gerade im Vergleich zu dem Verbrauch während der Betriebsphase. Ich habe mich dem Ganzen aber von oben herab genähert und geguckt, wie viele Bestandsgebäude wir haben und wie viele Neubau-Aktivitäten. Und da ist der Anteil wirklich sehr stark. Und das war im Prinzip Grund für die Aussage. Aber wichtig ist natürlich im Einzelnen und gerade in den Gebäuden, die wir jetzt errichten, dass sich das Verhältnis natürlich verschiebt.

JG: Ja, deshalb meinte ich, das ist natürlich so verkürzt auf diesen fünf Seiten so geschrieben, aber es steckt natürlich schon ein bisschen mehr dahinter. Aber natürlich hast du Recht. Indem wir den Neubau in Holz bauen, werden wir nicht unsere Klimaschutzziele erreichen. Sondern die Herausforderungen sind natürlich im Bestand. Und der ist nunmal so da wie er da ist. Und natürlich ist Abriss und Neubau auch keine Lösung, weil dadurch natürlich Resourcen verloren gehen und die graue Energie dann ja auch zerstört wird. Oder beziehungsweise allein durch Abriss und Entsorgung weiterer Energiebedarf besteht.

AS: Ja. Das ist gut, dass du das noch hinzugefügt hast. Super, gibt es sonst noch etwas, was dir dazu auf dem Herzen liegt, oder was dir dazu einfällt? Von meiner Seite hätten wir nämlich sonst die wichtigsten Punkte angesprochen.

JG: Genau, das andere hatte ich dir ja schon geschrieben. Mit den Zahlen, dass du da nochmal drauf guckst. Dass im Klimaplan dieser Energieverbrauch auf Heizung und Warmwasser definiert ist. Und du hattest in deiner bisherigen Erhebung Heizung und Strom zusammengefasst. Und Strom ist aber raus und meistens ist die Warmwasserbereitung über die zentrale Heizungsanlage, die ja dann mit Fernwärme oder Gas betrieben wird.

AS: Das ist wirklich in den meisten Fällen so, dass es über die Heizungsanlage ist? Weil ab und an wird natürlich auch mit Strom geheizt.

JG: Ja, eher natürlich in den Altbauten. Aber es wird ja auch nach und nach immer mehr umgerüstet. Also natürlich haben wir auch immer noch die Elektro-Durchlauferhitzer in den Bädern, gerade in älteren Bestandsgebäuden. Aber die Tendenz geht ja auf jeden Fall da hin, dass es entweder Gas-Etagenheizungen gibt, aber dann geht es natürlich in den Gasverbrauch mit rein. Und natürlich versucht wird auch eine zentrale Wärmeversorung zu bauen. Und das ist so ein bisschen schwierig, gerade wenn es auch Richtung Wärmepumpen geht. Dann ist das auch wieder Wärmeversorgung, aber über Strom. Das ist dann auch wieder die Grauzone dazwischen. Deshalb wird sich das dann vielleicht auch ein bisschen ausgleichen. Nur, dass du es richtig beschrieben hast und natürlich wird da auch eine Sicherheit mit drin sein. Und vielleicht gleicht es sich dann auch aus, aber dann ist es zumindest methodisch sauber.

AS: Das heißt, du würdest sagen, es würde ausreichen, wenn man einfach die Heizenergieverbräuche pro Quadratmeter ausrechnet und dann diesen Zielen gegenüber stellt. Danke für den Tipp.

JG: Würde ich so machen. Für alles andere bräuchte man erstmal eine Bestandsaufnahme, in welchen Gebieten mit Elektro-Durchlauferhitzern gearbeitet wird.

AS: Ja super. Dann auf jeden Fall danke für deine Infos.

JG: Gerne.

Appendix Q

Written Interview with Stephan Seiler

Time: received via email on 17.08.2018

Language: German

Interview partner: Stephan Seiler works at the BUE in the department of energy. He is the contact person for Hamburg's CO_2 balance.

Annika Stein: Sind Ihnen die dargestellten Informationen neu oder bereits bekannt?

a) Anteil des Wohngebäudesektors an den Gesamt-Emissionen; Schwerpunkt auf Betriebsphase, speziell auf das Heizen

Stephan Seiler: Ja

b) Hamburgs spezifische Energieverbrauchs-Zielwerte pro Quadratmeter

Ja

Was sagen Sie zu den Korrelationen:

c) Sind diese für Sie logisch oder überraschend?

Logisch bei Strom: Einkommen, Wohnfläche, Gartenfläche, Bruttogrundfläche), Rentner (Altersstruktur).

Erklärungsbedürftig bei Strom: Stockwerke

Rückfrage: Wie sind elektrische Warmwasserbereitung und Stromheizungen beim Stromverbrauch berücksichtigt?

Logisch bei Heizenergieverbrauch: Einkommen, Wohnfläche, Gebäudestruktur

Erklärungsbedürftig bei Wärme: warum Gebäudealter und Gebäudetyp nicht mit dem Heizenergieverbrauch korrelie-ren.

Rückfrage: Wie sieht es mit der Interkorrelation der genannten Einflussfaktoren aus. Welche Faktoren stehen möglicherweise dahinter?

d) Welche weiteren Faktoren wären interessant zu untersuchen?

Strom: Anzahl der Personen pro Wohnung

e) Sind bestehende Korrelationen für einzuführende Maßnahmen oder die Kor-rektur von bestehenden Maßnahmen/Schwerpunkten sinnvoll?

Grundsätzlich bestätigen die Korrelationen bestehendes Wissen über die Einflüsse des Energieverbrauchs im Gebäudebestand (Ausnahme Altersklassen). Sie tragen aber dazu bei die Einflüsse im konkreten räumlichen Umfeld besser abschätzen zu können.

Segmentiert werden Maßnahmen im Gebäudebestand bereits jetzt nach: Neubau/Bestand und Wohngebäude/Nichtwohngebäude

Darüber hinaus fehlt mir die Fantasie, wie die genannten Einflussfaktoren im Rah-men von Maßnahmen besser genutzt werden könnten. Am ehesten wäre vorstellbar, Öffentlichkeitsarbeit für Fördermaßnahmen in Bereichen mit besonders hohem Energieverbrauch zu konzentrieren.

Nutzbarkeit und Bewertung des Ansatzes:

a) Die Ebene der Statistischen Gebiete steht zwischen der stadtweiten und der individuellen Gebäude-Ebene. Halten Sie diese Ebene für sinnvoll?

Insbesondere für Visualisierung und Bewusstseinsbildung ist diese Ebene sinnvoll, da der Datenschutz gewahrt wird und gleichzeitig ein gewisser Bezug zum individuellen Verhalten gewahrt bleibt.

b) Bei der Darstellung handelt es sich um tatsächliche Verbräuche und nicht um berechnete Bedarfe. Allerdings waren für die Ermittlung diverse Annahmen notwendig, die wiederum zu Ungenauigkeiten führen. Ist die Darstellung der Verbräuche und Emissionen dennoch sinnvoll und nutzbar, um z.B. konkrete Ziele zu erreichen oder Anreize für lokale Maßnahmen zu schaffen? Besteht gegebenenfalls bereits ein vergleichbares Monitoring?

Die Qualität der getroffenen Aussagen ist für mich immer noch relativ schwer ab-schätzbar. Da die Datenqualität in ALKIS ja auch nicht besonders hoch ist, habe ich den Eindruck, dass insgesamt die Datenqualität allenfalls mittelmäßig ist.

Zur Bewusstseinsbildung finde ich insbesondere die Darstellung pro Kopf interes-sant, die den Energieverbrauch im Gebäudebereich in Richtung persönlicher Fußabdruck lenkt. Hier sind die berechneten Korrelationen allerdings auch nur eine Ergänzung, da jeder ja bereits jetzt den Anteil von Strom und Wärmeverbrauch Ansatzes berechnen kann.

Ein ähnlicher Ansatz wird mit dem Hamburger Wärmekataster, allerdings auf der Basis von theoretisch bestimmten Bedarfen verfolgt: https://www.hamburg.de/energiewende/waermekataster/

c) Sehen Sie Probleme darin, klimafreundliches Handeln geographisch darzu-stellen und der Öffentlichkeit zur Verfügung zu stellen?

Grundsätzlich ist Transparenz gut, solange der Datenschutz gewahrt bleibt. Im Ein-zelnen wird man sich bei öffentlich bereitgestellten Information anschauen müssen, welche Aussage von den Grafiken transportiert wird. Nicht alle Informationen nähe-ren immer auch eine konstruktive Diskussion.

d) Halten Sie es für sinnvoll, auch auf Bezirksebene konkrete Einsparziele zu formulieren?

Grundsätzlich ja, Voraussetzung wäre allerdings, dass tatsächlich Datenmaterial für ein Soll-Ist-Vergleich vorliegt. Dies bedeutet hohe Anforderungen an Datenqualität und Regelmäßigkeit der Erhebung. Außerdem ist ein solches Ziel nur sinnvoll, wenn es auch tatsächlich Maßnahmen unterlegt werden kann. Dazu müssten die Maßnahmen des Bezirks einen wesentlichen Einfluss auf das Ziel ausüben.

e) In welcher Einheit sind Ihrer Meinung nach Verbrauchsdaten am sinnvollsten zu verwenden: Energieverbrauch pro Quadratmeter / pro Einwohner THG-Emissionen pro Quadratmeter / pro Einwohner

Beide Darstellungsweisen haben ihre Berechtigung. Der Heizenergieverbrauch pro Quadratmeter ist als technische Größe bereits bestens etabliert. Die Werte pro Per-son zielen mehr auf das persönliche Verhalten und den Fußabdruck. Weniger ein-leuchtend finde ich Strom- und Energieverbrauch für Warmwasser pro Quadratmeter.

Appendix R

Transcript of the Event "What is possible? Pathways to Zero Emission Buildings"

Time:	11th November 2017 at 1.15pm – 2.45 pm
Place:	Meeting room 2 at the Boon Zone of COP23 in Bonn, Germany
Setting:	Part of the "Human Settlements Action Day"
Organizer:	Marrakech Partnership for Global Climate Action as part of UNFCCC, Contact person: Nora Steurer (UN Environment / GABC)
Recording available at:	https://www.youtube.com/watch?v=blqNp4voAdw from 3:27:40 to 4:39:33
Transcript:	By Annika Stein, 26.11.2017

Figure 148: Illustration of Participants at the Event „What is possible? Pathways to Zero Emission Buildings" in Bonn, 11.11.2017 (Author, 2017)

Participants

Name		Position
Ms	Martina Otto	GABC/Head of Cities Unit at UN Environment
Mr	Yves-Laurent Sapoval	Senior Advisor, Ministry of Ecological & Inclusive Transition (METS), France
Ms	Elizabeth Beardsley	Senior Policy Council, US Green Building Council
Ms	Ina de Visser	Head of the PEEB project, Department for Sectoral and Global Programmes, GIZ
Mr	Brian Dean	Head of Energy Efficiency, IEA
Ms	Soledad Aguilar	National Director of Climate Change, Ministry of Environment and Sustainable Development, Argentina

Name		Position
Ms	Andrea Heins[I]	Undersecretary for Energy Efficiency, Ministry of Environment, Argentina
Mr	Ralf Niebergall	Vice President, Federal Chamber of German Architects
Ms	Elizabeth W. Chege (Moderator)	Chairperson, Kenya Green Building Society

Elizabeth W. Chege:

Hello, good afternoon. Thank you for joining us this afternoon. We are now going into the session called "Opening: Human Settlement Round Table - Setting the Stage – Impact and Potential of Human Settlements". This is the session one "What is possible? Pathways to zero emission buildings". I am Elizabeth W. Chege from Green Building Society and the African Regional Network Vice Chair Person for Green Building Council.

Our speakers will introduce themselves, quite shortly, but we'll start with Martina Otto to give us some feedback from sessions we had from the Global Alliance of Buildings and Construction on Thursday. Thank you.

Martina Otto:

Hello. So, warm welcome also from my side. And as we said- no, this is just clicking through-, so as Elizabeth said, we already got together two days ago and we had a full day discussion on buildings with a very, very full room and a lot of experts from really the different facets that matter in buildings around the table.

So this is really meant to give you really short feedback on what was discussed.

It was organized and under the auspices of Global Alliance on Buildings and Construction [GABC, cf. Box 1]. That is a partnership that gathers over a hundred partners. Twenty-, well, a forth, of which are governments and then local governments as well and think tanks and civil society and private sector. So very broad variety. Again, to reflect the breadth of the actors, that actually need to work together to move something in this market.

And here you see-, I mean the motto is "towards a low carbon, energy efficient and resilient buildings and construction sector". That's what we're working towards to harness the huge opportunity that there is in terms of climate mitigation.

[I] Comes to stage spontaneously during the discussion

So without the building sector we will not be able to meet the Paris Agreement and I think that is the message that we all need to keep in mind. That's something we need to take home. We are working actually to realize the potential.

That's the membership, I already mentioned that. Very quickly: We have five main work areas that we identified as being critical. And moving ahead, that's awareness and education, public policies, market transformation, finance, measurement, data and accountability. Our program was structured around those areas as well. We have a number of lecture products and that's the global road map that was done, so that's really on the policy side.

We're at the moment going through a **regionalization process** for regional round tables to really look into the priorities that there are. At a more local context to factor that in, so really priorities that need to be embedded in the round table to help the policy makers to drive this agenda forward.

And then we have a **global status report**. The second edition will be coming out on the 11th of December with a couple of really good key findings [cf. Box 2]. It shows the trends in this market and very unfortunately it shows us as well, that we are not quite there yet. And that is not because we have not made any effort–, we have. There is good progress: We have 132 countries that have embedded buildings in their NDCs [National Determined Contributions]. But it's not concrete enough. It doesn't suffice, because the other thing is that the floor space is being added at a much faster scale than the emission reductions are taking place. So if we are not careful, if we don't double our efforts, we will only see the emissions double. And that is something we absolutely have to avoid.

So now with that introduction, the recommendations from the symposium that we held:

Public policies: absolutely critical to enable also the private sector to do their bit. We said we really need to make a greater effort to include energy efficiency in buildings in the NDCs. And really precisely, with concrete policies, with projects that follow through, rather than loosely mentioning them. And it's really to varying degrees already reflected, that we need to do a better job.

The next bit is really the **enforcement** as well. And here we have to look at how we can forge the local alliance. We have a number of partners that have started doing that. The have national alliances for the global construction sector, that bring together the different players. And that's actually quite powerful because it forges that understanding the common vision that is needed to move forward.

We need to make sure that the public policies are long-term and harmonized. Obviously, the buildings are there for a long time, so long-term policies are here critical, too.

We talked as well about the need for **vertical integration**. So really the feeding in from the national to the regional to the local levels.

And we talked about the **power of targets**-, to have concrete targets. They are not easy to put into place. It takes a lot of political will. It is a risky business, but it is really needed to give the right signals as well.

Talking about the right signals, it's about the leaders that drive market impact, such as carbon pricing, but also starting at home with public procurement. That is a huge leader as well, that should not be underestimated. And of course, with a very limited number of actors, so we can drive a change, meaning the national as well as the local governments.

Then there was a group on **transforming markets**. And here the emphasis was very much on aligning the value chains. So, rather than looking at separately building materials, we need to look at the whole, because otherwise we run into the risk of sub-optimizing the overall performance. So really taking a more holistic point of view. To do that we need to start really mapping the value chain, to know what we are talking about.

Then we talked about the need for the **targets to be science-based**. We also need to avoid the circle of blame, saying "Yeah, I am doing this, but the others don't follow through". So everybody has to do their bit and basically work together.

On **finance** we said, we have to really work on our narrative. That makes a compelling story for the climate sector to follow what we think needs to be done and what the policies would prescribe. That means we need to connect the planet's needs to the regulatory framework to build capacities for accessing and using finance instruments. We also need a project preparation pipeline. So that once we have the financing mechanisms in place, that the projects demand for them to pick up. So we need to really unlock the funds that are actually available. With climate funds and so on, that we make sure that the building sector gets its share, that is commensurate with the mitigation potential that we have in the sector.

Last but not least: **data**. And that's a call! We should have actually started with data, because that is sort of the basis of everything. If you don't know what we are talking about-, I mean if you don't measure it, how can we take the right kind of steps? So that is really important. We need to create a common language here. Because sometimes we talk about-, they have the same name, the things, but what is behind it in terms of the methodologies? It is not really the same. Something as simple as "What is the net floor area?" is defined differently in different contexts. As long as we don't know, we don't know what in the end we are talking about.

We need to make sure that the access to data is permanent and easy to use. It is an access question and a usability question. There was a suggestion to look much more into open-source data as well. That goes hand in hand with the need to ensure, that the data is of good quality, obviously. If that's not good, what comes out is not good, either. We need to look at building data as a public good. That goes hand in hand as well with the idea of the open source data.

I hope I have done justice. I mean, this was a run through to a whole day of even parallel sessions and so on. A number of you were there, so if there is anything that I have forgotten and that is absolutely critical, please say (laughs)-, say so. I think in the discussion we will have more time to do that.

Thank you.

(Applause)

Elizabeth W. Chege:

Thank you. So that is Miss Martina Otto, head of Global Alliance for Buildings and Construction, secretariat, and head of Cities Unit UN Environment.

You can see how passionate she is about that. And we actually have very, very concrete discussions and we had concrete discussions on Thursday, so we are encouraging a lot of participation from the audience today.

So we'll move on to the introduction from Miss Ina de Visser, head of Project, Department for Sectoral and Global Programmess at GIZ [Gesellschaft für Internationale Zusammenarbeit].

Ina de Visser:

Thank you very much. Yes, I would like to introduce to you the **PEEB program** [Programme d'Efficacite Energetique dans les Batiments], which is the program for energy efficiency in buildings. For me it was very good to see this presentation-, the run through we've just heard as a background. Because this is something that really adds on to this and starts especially on the finance and the policy side of that.

So, I am glad to see here-, that seems a good fit. So, the program for energy efficiency in buildings or PEEB is a French German joint initiative. It is meant as one of the first implementation programs related to the Global Alliance for Buildings and Construction. It is set up with funding from the German Environmental Ministry, the BMUB [Bundesministerium fur Umwelt, Naturschutz, Bau und Reaktorsicherheit], the Environmental Ministry of France is involved, and the French Environmental Fund. Also on the implementation side at this moment-, it is implemented by French and German initiatives together, or institutions together: From the German side GIZ, from the French side we have Adema and AFD [Agence Francaise de Developpement]. Where you see a very nice fit also, having the bank and the technical assistance sides on board.

The objective of the PEEB program is to minimize energy use in buildings and construction. It is especially focusing on new buildings and on bigger developments, so investment volumes fifty million Euros and up. The activities, the idea is that there is funding available. Might not always be easy-, I'm not gonna say here that there is unlimited funding for every program, but there is funding available. But it's not so easy to get to. It is also not so easy to develop a project that is easily taken up by banks. That I think is realized by everyone. So, the activity is to link the project and the finance side.

First of all, this is **technical assistance** to projects themselves, to private sector and to governments. Also technical assistance to improve policies, as that was also mentioned before. There will be capacity development in the private sector. There will be some work on knowledge management and dissemination and I think the Global Alliance of course is the perfect vehicle to reach out beyond the initial countries where this initiative is working. And it will be working on the development of financial tools. And I think this is also a very interesting subject, because loans are not always the best way or are not always developed or implemented in a way that they fit at these kind of construction projects.

Grants of course are interesting for any project developer, but not always at the most efficient way of implementing the money or spending public money. Because we are talking about public money here. So there will be looking into PPP [Public Private Partnership] ESCO [Energy Service Company] models, performance based contracts et cetera.

For this moment the countries that have signed up for this and into these activities are–, and I have to look here on my map–, Morocco, we have Mexico on board, Senegal, Tunisia and Vietnam. So these countries have expresses their interest. I think all of them have now sent their letter of intent. They want to be on board here. So they will receive this assistance from the German and French stakeholders to improve their policies, to improve their projects et cetera and access money.

At this moment, this is a French German initiative, but this definitely is something that could grow into something bigger and that I want to make you all aware of. This is something that can grow bigger. This is something also that is set up in a way that it will be relatively easy to grow bigger. So both, on implementing and funding side, this is not something that should stay confined to the stakeholders. It will be in a developing stage now, in a learning stage, but we will definitely welcome more governments on board, both on the implementation side and on the funding and management side.

So, thank you.

(Applause)

Elizabeth W. Chege:

Thank you for that. If I may request, we have Elizabeth Beardsley from Senior Policy Council, US Green Building Council and to introduce Advancing Next Zero. Thank you.

Elizabeth Beardsley:

Thank you so much. It is an honor to be here. Thank you to the Global Alliance and thanks to all of you for taking time out of your day.

First, a quick introduction to the US Green Building Council. We're a mission based, non-profit organization. And our mission is to transform the built environment to one that is safe, healthy, inclusive, productive, efficient, equitable, sustainable and resilient. We do this through all of our platforms and initiatives.

The LEED [Leadership in Energy and Environmental Design] rating system is our most well known, our flagship and has helped raise the bar for sustainability of buildings and creating new markets, new market drivers. We now have LEED projects in over 160 countries with over half of our new project coming from outside the United States. And we are certifying more than two million square foot per day. And about two thirds of LEED credits have the specific intent to help reduce human contribution to climate change.

So we're all here with the common recognition that we need to do more to push our buildings to come close to reaching that net zero goal. We need to get to 80 % of buildings, including existing building stock, at net zero. And that's a big challenge. One of the pathways to do this, is through a **net zero certification** or verification to help provide a label or way to recognize those high performing buildings.

And we're excited to be collaborating with Green Building Councils [GBC] around the globe and the world's GBCs advancing net zero projects. With this project we endeavor to encourage and recognize projects that achieve net zero and Green Building Councils in Australia, Brazil, Canada, Croatia, the Dutch GBC, Emirates, France, Germany, Spain, South Africa, India, Sweden, the UK, and ourselves, the US, are participating. So it's a great list and it is growing.

I am especially pleased today to share with you the US GBCs net zero carbon verification. And we are offering a verification that a building is operating at net zero carbon. Our carbon verification is simple. It acknowledges net zero achievement across energy, transportation, water and waste through year's operation. No prerequisites, just verified data.

Definition of a net zero carbon building

And we define a net zero carbon space as a building for which over twelve months on source energy basis carbon emissions of consumed energy, of consumed water and building-related transportation and waste is less than or equal to a voided carbon emission value of renewable energy that's added to the grid from on-side exports and direct actions calculated on the basis of the recipient grid.

Not a mouthful, but basically what we're saying is that we're encompassing a number of building operations that do add to the carbon footprint of the building beyond energy. We are considering the grid that it is being drawn from as well as the grid that renewable energy is being added to, to get the most accurate presentation we can. The verification available through our Arc platform and we'll begin by first offering this to LEED certified buildings. We are taking into account energy losses in the grid as well as how clean or dirty the grid is.

By including the other elements of water, waste and transportation that gives a better picture of how the building's operations are performing overall and really contributing to carbon emissions.

We'll start with our best available estimates for the water and waste carbon transfer values and we'll define those over time as more data becomes available. Including these parameters it's critical to send a signal that all these operations matter.

Our net zero verification uses the LEED credit rules for use of off-site renewable energy through green energy and renewable energy credits. And no offsets.

The renewable energy must be causal and we see this evolving over time to better incorporate insurance that renewable energy truly is offsetting fossil fuel generation on a grid.

Lastly, as we proceed with net zero, we are playing all of our tools, and we have pulled together resources on a single location on our website including over a hundred on-demand courses to learn more about net zero and practices that can be included. And we'll be adding case studies and other opportunities. With our **growing suite of rating systems** as well we are going beyond the building to start to recognize sustainability in other areas. This includes sustainability for electric grids with our PEER system, manage landscapes with SITES, zero waste with the TRUE system and parking facilities with Parksmart. Each of these was developed by experts in the respective area and we are helping them to scale up and to bring them to more buildings and more facilities and more cities around the world as solutions.

We're excited also to partner with IFC on the edge program and with the Investor Confidents Project.

So, we are really excited to talk more about how we push forward on net zero and thanks again.

Elizabeth W. Chege:

Thank you, Elizabeth.

(Applause)

Since Yves-Laurent is next to you, please shell we have your introductory message, please.

Yves-Laurent Sapoval:

I was supposed to be the last one here.

Elizabeth W. Chege:

It's okay, since you are sitting next to the microphone-

Yves-Laurent Sapoval:

I have to think about what I'll be saying, so-

Elizabeth W. Chege:

We are working out how it works, sorry. (laughs)

Yves-Laurent Sapoval:

Okay. Sorry for that. Okay, so- (laughs) Nice surprise. Ask me a favor next time, thank you.

So, uhm, basically I would say-. Because the question, it has to go: "What is possible?" There is several things possible. I just want to also do the questioning instead of really talking about what I will be talking about afterwards.

The first thing is: "What is possible?" (…) "What do we wish?" We wish to **gain some more visibility** for the building sector within the question of climate change. So this would be the first thing, what is possible. This is possible. Gain some more visibility for this sector. That is, just as Martina said, a really heavy weight of the question that we all in the Global Alliance think that it's not enough on the top of the list of the questions, okay. So that would be the first point.

Second point is, what is possible, is to act. I am not going to talk to you about what we are doing in France. On every paper, of course, we are doing very good. (laughs) Any question? (laughs) So I'm just going to tell what we are doing within the Global Alliance. (…) We're raising with also the Clean Energy Minister Initiative, that will be a few things.

One is getting **governments' involvement** and commitment within like very simple commitments, like within four points that we'll be having a strategy including their building sector in their NDC, which is not gained at the moment, as Brian is probably going to say something about that.

Second thing would be that they would **build and raise local alliances**, because we think that's the only way to really go forward, associate all the stakeholders, local.

Third thing would be to have some-, a certain number of **exemplary buildings** both in the deep retrofits and zero net building or energy residual buildings.

And I forgot the fourth point, but it's-, I'll find it later.

Yes, to have a proper, a harmonized **database**, because we were missing data and harmonized data. So that's what we would be aiming to have in terms of commitments of governments.

The second thing we are doing within this second pane is to have a high-level meeting in Paris on the 11th of December in gathering lots of high-level people about final energy efficiency buildings. So we are organizing this with the European Commission, the UNEP FI [United Nations Environment Programme - Finance Initiative] and lots of others.

And then-, so this is going to take place on the 11th of December before the 12th of December, as you know there will be a very big evennement on climate in France.

So basically that's what we are doing. On this initiative we are also trying to gather a next built data base. This is something else. We have to identify relatables in each country, if you have some people to-, (laughs) that could be recognized experts, that discuss this question and have a real network, worldwide network on that question.

So I am now getting to the proper-, what I was going to say at the beginning. So what I was going to say at the beginning is to present our energy positive and carbon footprint label that we're developing in France. So we had this energy label with four steps. We have this, but then we saw that energy is not the only question and the carbon footprint of the building should be assessed also. So what we are doing here, is we are developing an **"E plus C minus" [E+C-] label**, that is taken into account one side the energy demand and the energy projection of the building, like saying "Okay, you can use some energy and also produce some energy. Let's do the in and out assessment give you a label on that".

Not only the topic of energy, but the entire carbon footprint of a building needs to be assessed.

And on the other hand we are working-, associating a label on global carbon footprint of the building. Taking it from the extraction of materials to production to transport of the materials, construction, of course the use of the building and then destructions and treatment of waste. So this is what we're doing in this new label that is "E plus C minus". There is no slides, but you might find them on your demand.

We have already about five hundred buildings that are getting into this labeling. It's now an experimentation, because we want to experiment it with all these stakeholders before we get to renewable implementation. It might get to a new reglementation and stuff by years, but by now we are experimenting with all volunteers and we think it is very promising.

So I wanted to give those two examples of what is possible. It is possible to get some more visibility on the global level to try to work with governments and push this question. And also everybody has to do his own work. So that is what we are doing within the label "E plus C minus".

That's all.

Elizabeth W. Chege:

Thank you Yves-Laurent.

(Applause)

That's quite a bit happening already.

So we will last talk to Brian.

Brian Dean:

So I am actually Brian Dean from the International Energy Agency [IEA]. I work on Energy Efficiency in buildings. Unfortunately Brian Motherway was not able to join us today, but I am happy to fill in for him.

So, in IEA's work along with the GABC with tracking energy efficiency progress in the building sector, what we are finding is both: positive trends but also negative issues that we need to address. Particularly what we see is that the **building sector is currently not on track** to achieve a two degree scenario. So that's very clear.

What we are also seeing on the negative side is that **policy progress in the last year has essentially stalled**. It has not kept up with the policy progress that we have seen in previous years. This is the concerning aspect.

Now, of course, as Martina mentioned, we are seeing energy efficient buildings-, buildings becoming more energy efficient. The energy intensity is going down, but population growth and economic growth-, we are seeing that **the energy sector is continuing to grow**.

At the same time we are seeing positive trends, which is: Energy investment in buildings has increased-, increased another 9% this year to over $400 billion. But the concern of course is, that this is still a very small portion of course of the trillion that is spent on buildings every year-, building construction every year. So we are looking for ways to **shift investments from regular buildings into energy efficient buildings**, from energy subsidies into energy efficiency. And those shifts in investments could really bring us toward this two degree path.

So, a new analysis that we did for the global transport this year is looking at: What would happen if there is a ten year delay?

Recognizing that if policy is not making progress right now, there is going to be an impact. So what we looked at is the ten year delay on energy efficient envelopes. And with just a ten year delay, what we see is that by 2050-, if exactly the same buildings were in place in 2050, but there is a ten year delay on putting those buildings in place, we would spend an additional three years of heating and cooling energy consumption. So just for the delay alone. So if policy is stalling right now, we don't want it to stall any longer. If investments are stalling, we don't want it to delay any longer. We need those transitions to get to the two degree path. So that's what we are finding at the IEA.

With a 10-year delay in retrofitting building envelopes, by 2050 we will have used an additional amount of heat energy equal to 3 full years of heating.

(Applause)

Elizabeth W. Chege:

Thank you for that. We will summarize more of what you actually mentioned. 'Cause it's a bit worrying and as well as we have the opportunity right now to actually move it forward.

So, using the list, we'll have Professor Ralf to introduce himself and give us a bit of an insight on the pathway. Thank you.

Ralf Niebergall:

Okay thank you. Thank you for inviting me. Because I must admit, I'm a little bit scared here in this round of experts, because I'm simply an ordinary architect working for ordinary clients, apart from this also the Vice President of the Federal Chamber of German Architects, responsible for European and International issues. So I'm not an expert, but this helps perhaps to widen a little bit the view on the things.

Because what we feel as architects is that we are **too often focused on technologies only**. And therefore we say we must take a more holistic approach. When it comes to zero emission buildings from a technological point of view, we can say that it's not a rocket science anymore. But to convince our clients to do more-, because their first interest is not to save the world, of course. They want good living conditions for their occupants or good revenue on their investment. This is what we have every day to consider. To find a way between these technological issues and what is really needed. I think for this, architecture is a crucial point.

It starts from the layout of the building, which should be optimized on the one hand, but should be thought also of the well-being of the occupants and to people, who have to live and to work in this. And this we take not often enough into our consideration, I think.

There is no thing as wrong behavior. Buildings have to be designed in a way that they suit the behavior.

What we also always face is the so-called **performance gap**. And then we blame the occupants and the users: "You behave in the wrong way." But I always say: "There is no wrong behavior!" (laughs) We must consider the behavior and find solutions that people can behave as they behave in their flats or at their workplace. And we are really still energy efficient. This has to do also with technologies. We must consider both sides.

Plus energy buildings could „help“ buildings with a low performance.

The third point I want to make is, as I said, to build a new energy efficient or even zero emission buildings-, not a rocket science, but what's much more complicated is dealing with the **building stock**. When it comes to the building stock, we must look also at cities using for instance plus energy buildings to support other buildings that doesn't have this performance.

And to consider also the **social impact**. Because we should say: Yes, renovation of the building stock to a much higher extent than nowadays is absolutely important to reach the climate goals, but we must consider the people who are dwelling there-, is it still affordable for them? And to find here the right balance. I think apart from the question of reducing urban sprawl, higher density in the cities, should be our main issues. Not only technology. Thank you.

(Applause)

Elizabeth W. Chege:

Thank you very much. We'll now have Miss Soledad Aguilar, National Director of Climate Change, Minister of Environment and Sustainable Development, Argentine Republic. She'll have a couple of slides, but we'll just share the clicker. Thank you.

Soledad Aguilar:

Hello? Thank you. Well, a lot has been said already. So I just wanted to share the experience in Argentina with the National Cabinet of Climate Change. We have the participation of 17 ministries and we are working on the measures to implement our NDC.

So, what we see here is the result of our last inventory that we did last year. And as you see-, I don't know if you read Spanish-, on the right side, **the residential and commercial sectors, which is mostly buildings, represents more than around 16 or 17% of our whole inventory**. And it includes the energy used in the buildings, the fuel that is burned in the buildings for example for heating, and the wastes that are generated by the buildings. Of course, it's interesting, it was mentioned before, that we should also count also the construction of the buildings themselves. Those up here lower down are industry, because we take it as the construction industry. So it's even more than that 16 or 17 % of the inventory. So that shows that this is a very important issue to deal with when we are deciding our NDCs.

Last year we did this inventory, that I was showing, and also we worked on revising our NDCs together with all the ministries in the national cabinet of climate change, that was created last year. I was also mentioned that the Ministry of Environment also was created right about the same time that the Paris Agreement was signed.

So, within our National Contribution during our last year, we worked with all of the ministries, but mainly with the Ministry of Energy, in revising our NDC to make sure that the measures that were calculated inside our NDC were aligned to the priorities of the new government and especially of the Energy Ministry.

So, as a result of that revision, we came up to a part of our NDC, which is the energy part, and that is planning for the reduction of 77 million tons of carbon dioxide equivalents by 2030, at 2030. So this is the annual reduction.

In order to reach that reduction, we worked on a set of measures and the round table that deals with energy-, the **energy round table** in the national cabinet on climate change-, decided to work on energy supply and energy demand aspects. So, basically for our issue today, we are mostly interested in the ones that have to do with energy efficiency on the demand side. So we calculated the reductions for measures in home appliances: boilers, solar boilers, which are-, I don't know if that translation is correct-, so solar heating systems, heat pumps, energy efficient heat pumps, water saving devices, efficient lightning in residential and street lightning, and the one that has more to do with construction is the thermal insulation in buildings.

So all of these measures were calculated. Some applied to existing buildings, some are, for example thermal insulation is mostly for new buildings.

As a result from those calculations, we came into this year's work, which is to build a road map for each one of these measures. And this the work that we did this year and this was done with the ministries in the national cabinet, in our energy round table, but also expanding the round table to the industry, the private sector and academic sector and NGOs, in order to make sure that the road maps, that were being designed, included all the issues and all the barriers, that need to be overcome, like you were mentioning before, from the developer's point of view and from the user's point of view.

So now we have a **national energy and climate change action plan** that was finalized last week before coming to the COP. And that includes all the roadmaps for each of these measures and so now the most difficult part comes, which is to start measuring, if the measures we-, first, we have to implement them, make sure they are implemented at the provincial and the municipal level and then to be able to monitor the advances and the reductions and see if our calculations in terms of the potential reductions effectively can be shown as part of our inventory.

So, that's the work that we have ahead. Well, and we'll see how this goes in the next few years.

I just want to make to mention that our under-secretary for energy efficiency is sitting here, Andrea. She knows much more than I do on this topic, so if anyone has questions, I'm very happy that she could join us and you can ask directly to her.

Thank you very much.

Elizabeth W. Chege:

Thank you very much.

(Applause)

Elizabeth W. Chege:

Thank you Soledad. I'm just wondering: Are we all on the same page on **what net zero is**? I think it's going to be the first question. Have we agreed internationally that holistic approach on net zero? We have defined it, so that we can actually have pathways. Who would like to take up as a first question? Perhaps, Elizabeth?

Elizabeth Beardsley:

You can speak to the World GBC and see the net zero program, where the parties agreed on a common set of principles. So, a building must be **highly efficient**, there is a hierarchy for **renewable energy to start with on site and then move to off-site**. The key metric for our group is carbon, not energy units. And I think from there, we have seen some variations from country to country that reflect local markets as well as local grids and energy sources.

Personally, my own opinion is, that that's okay. That we need everything-, we need everything in, if we are going to meet our goals. And that it's more important to get **positive activity**, to get demonstration buildings out there and built to get more people excited about the concept of net zero and even just measuring their carbon and paying attention. So to me the bigger play right now is to get these out there and to accelerate activity and help that connect with policy.

Yves-Laurent Sapoval:

Yes, I would say, the answer is no, but that's not the real question. The question is to act, I mean if you do good, there might be some differences, but the question is (…) let's do good, let's go ahead and do things. Cause the afterwards you get some perfect measurism, you get some perfect assessment and everybody will be able to say: This is to this point and we will not be using extra Joules and kilo tones and I-know-what kilo Watt and I-know-what (…) Okay, but the question is, you know, if we wait for that, I mean we are all dead, so let's go on.

Elizabeth W. Chege:

I can see some reactions already, so we'll share the microphone. Share this one?

Man 1 from the audience:

Yes, thank you. My name is Tom Margare. Working with Yves-Laurent for the French Ministry. I've had quite an extensive experience in the energy shift in buildings at the French, European and also International level.

I fully agree with all of what was said, of course, but from my experience, I think that energy efficiency in buildings-, energy efficiency elsewhere too, but especially in buildings-, is always jeopardized, because there are kind of attempts to grab the money. Everyone wants to grab the money. So we talk about low-hanging fruits, you know, there's technology that is the most efficient from a financial point of view. That of course very interesting to know about them.

But on the other hand, it's very important to stress that we have a long-term goal. And **this long-term goal should be carbon neutrality**. So carbon neutrality-, what does it mean? It means that all possible solutions are implemented at the same time. Not at the same time, but I mean, they are all consistent with each other and at the end of the rule, everything is just implemented. Rightly implemented.

The problem is that if we don't *secture* something out the building envelope, than it becomes very difficult to just stay on track with this long term existence. And when I said that energy efficiency is always jeopardized, you will hear always of someone with a silver bullet, saying "Okay we have really great heat consumption" for instance, or "we are going so very long with photovoltaic". And they make you think that yes, it's the solution. But in fact, the solution-, **there is not one single solution**. Because otherwise you won't have the problem treaty as a whole and you will just push the solution and not the problems at another scale.

So, I would really strongly advocate-, and we have been discussing this yesterday, on Thursday at the same podium-, so I would really advocate the we put an emphasis on this what we call passive, energy efficiency solution so that buildings designed in the whole of architects and engineers it's just crucial and that the building design and also the materials and the envelope is secured. And then all the rest is natural, because if we want to go to carbon neutrality, we need advanced technologies, we need the renewable energy, but all of that should be very consistent with this very first break that is the energy envelope.

And that to me-, those of you that have something to say about that, that would be great. Now I can touch the microphone. (laughs)

Elizabeth W. Chege:

Thank you, thank you. A couple of notes there. You mentioned the passive design opportunity and also there was a discussion from the professor, saying designing net zero is not rocket science, it's the existing buildings that we also have to consider.

I mean, I thought from Africa, it is that 80 % of the cities in Africa haven't been built yet. So, great opportunity on that matter.

So, there is a gentleman over there with a microphone and then we will come to Vincent. Thank you.

Man 2 from the audience:

Okay, Laurenco Palliano. I teach building physics in the engineering faculty in Milano. Just to offer a compliment to your question. To secure that, every opportunity is useful. For example in Italy, the zero energy performance certificate is based on free quantities, energy need for heating, energy need for cooling. So two elements which qualify the quality of the envelope-, the first thing that was mentioned. And the primary energy to secure the quality of the technical systems and the supply.

Primary energy is calculated net each month rather than net over the year. So you have to be good at using energy month by month, which is obviously easier if you use a low amount of energy, because we want the building per se to be high performance.

Then the **change of the grid** can be also a burden for the grid because if you produce a lot in summer and then you produce renewables in summer and you use fossils in winter, obviously you are giving to the grid a big cost and role to be sort of storage for inter-saisonal storage, which is very technically difficult and costly.

So we try to concentrate on the building per se first to be efficient month by month, efficient and using renewables month by month. Just an example of how to decline those two things, energy needs and primary in that concrete case.

Elizabeth W. Chege:

Thank you. Vincent, please.

Man 3 from the audience:

Thank you very much. My name is Vincent Kizirah. I work for UN Habitat. I just want to say that the net energy, net zero energy building, for me it's just a mile stone in the transition towards low carbon buildings.

The reason why I'm emphasizing on this, is because we are assuming all of us know what is sustainable building, which is not true. Just ten years back, any school of architecture will be teaching the traditional architecture. That is the type of architecture we are seeing outside there, that are really very energy consuming. So, we are assuming that everybody, even including the student of Architecture, they know what we are talking about.

So, I'll just say that, what I have not heard from the panelists is **how are we building the capacity of the future architect** of tomorrow? Because those are the one that will be required to design sustainable, low carbon, even carbon neutral buildings. This is not happening. And perhaps we need to put more emphasis on that.

To deal with the government is rather something easy to do that. Because what is happening is that in the last let's say five years and perhaps in the last three years, after the Paris Agreement-, a lot of government went back to their country and said now asking? "What is that about green building?" And now you start saying that green building been put in the agendas. So we want our building to be green. But who knows how to build them?

So that is very for the government is possible. Local government also, they are also trying to even develop their energy strategy, where by they are also trying to make sure that their consumption are also environmentally friendly.

But again, the problem is the supply. The demand may be there, but do we have enough supply to respond to that? You just mentioned one thing. In the developing countries, they are building that will be standing in 2050 are 70 %. They are not yet being built. Is it possible to make those building, at least to make sure that we don't follow the same mistake (incomprehensible).

So, perhaps **in Europe the building stock of today need to be improved**. **But in other part of the world the new buildings, this is where we need to address**. And how do we address that? And perhaps one of the way is really capacity building. From the school, I don't know what is happening in Argentina, because I think we really need to start from primary school, technical school and also university. So that when the engineer come out from the school, they are able to design what we all want to see happening tomorrow. Thank you.

Elizabeth W. Chege:

Thank you Vincent.

(Applause)

We have Yves-Laurent, who mentioned about an expert database, a national one or across the countries to also help answer us the question towards capacity building.

Yves-Laurent Sapoval:

Oh-, that is not what I was going to say, I'm sorry. I just want to say that this is a very important and good question. I'm going to say two things.

First thing is that we have to take into account, that for architects, this question of energy efficiency and the question of the façade of the building being the difference between inside and outside the building, is a crucial revolution, as important as the revolution that was the one when concrete was invented. When the concrete was invented, it was a revolution because the weight of the building was not on the façade anymore. So, it was, it can be lots of work for architects to adapt and they in some way considered it as something very caring for having a new architecture. We met some in CIAM [Congrès Internationaux d'Architecture Moderne], Congress of Modern Architecture, that were mainly to take into account of this question of having the concrete getting into the building and not having a building in the same way.

We are facing for architect I think such a revolution now. It's a real question. It's a question, that has to be taken into account and I think you made your point, it's very true.

Second thing is this: **architects are working for the well-being of people inside the building**. So the question is, all we are talking about, like net zero building, it is not getting I mean it is not getting pleasure to people. It is not getting well-being to people if nobody links this with that. I mean, it's not energy efficiency label, is something- (…) Well, if I buy a house in France I will have an energy efficiency label, so probably I would ask myself how much I will spend on heating. That's my question, the A, B, C, D helps me to know that I am going to have a heavy or a low weight of heating, that's all. I mean, it tells me nothing about the pleasure of being into this house. So, this is the question.

Besides public policies, consciousness about energy efficiency and labels the well-being of the users of a building is an important and underrated driver.

And also, what we have been saying about our partners here, lot's of partners I have been talking about that. That pleasure, the well-being of being in the building is a question that should be addresses. This is a real driver. We've always been thinking that drivers are public policies and energy efficiency labels, and consciousness of the fact that energy efficiency is important. But pleasure to be inside a building and a well-conceived building, that would be efficient because of that is something that is not enough assessed. I guess, by now it is a real driver.

That's all.

Elizabeth W. Chege:

Thank you. I think we had another reaction. Thank you.

Soledad Aguilar:

So I am going to apologize, because I have to go to another event. But the secretary of energy efficiency can come to my place and answer the question. She is Andrea Heinz and she is the expert, thank you.

Elizabeth W. Chege:

Thank you. We'll let you off on that one. (laughs)

Soledad Aguilar:

Thank you and I apologize.

(Applause)

Andrea Heins:

Good afternoon everybody. I want to answer the question about education.

In Argentina we are working hard in including education in the-, include energy efficiency in formal education. Not only university but also in primary school, medium school. With the respect with universities, last year we call all universities of the country, national and also public and private universities, the universities that has engineering and architecture careers. And we asked them to work together to build a proposal to include the energy efficiency in the existing current years. We don't want to have a new career about energy efficiency, **we think that energy efficiency have to be include in the existing careers**. The future architects, the future engineers have to be teached about efficient construction, how to build a house in a efficient way. And now, a year after that call, we have a document, I think that there is 50 % of the universities work together and put in their ideas in the report. And the report includes a proposal to include energy efficiency formally in that careers and the next steps are to give that report to the formal national commission for the creditation to that careers and to go ahead with the proposal.

But we are very concerned about the education and to include energy efficiency in formal education. And I am working on that way.

Elizabeth W. Chege:

Thank you. Thank you very much.

Professor Ralf from the federation of architects.

Ralf Niebergall:

Yeah, it's a question I ask myself really every day when I'm teaching. What is the right way of teaching? Because for instance in our international master course I have a studio with ten people from ten different countries from four different continents. As you said, it's really true, the problems we have in Europe concerning the building stock are absolutely not your problems. I learn really every day for instance we as Europeans adore-, if again Europeans work in Africa or in Asia with rammed earth buildings and mud brick, telling them you should go back to the roots. And then tell us, this is not our problem. If Africa for instance, cities explode and we need high density and we need high rises, then we can't build it in rammed earth or in mud brick. This is really the only thing is, we can't teach a certain strategy, but **we can at least teach awareness**, awareness of problems. And we try it in a playful way. For instance, just to build in reusable materials and looking what's coming out. But really, it's true that it is every day a new challenge.

Elizabeth W. Chege:

Thank you. Just as we come over to you. I think this is one of the other things that we noted as coming from the Global Alliance for Buildings and Construction, and Miss Martina mentioned, is that when we are talking about education and capacity building, it's, not just architects or engineers or the real estate sector. It's the financiers as well, 'cause they're part of the discussion.

So I'll hand over to you. You had your arm up? Thank you.

Man 4 from the audience:

Yes. My name is Andreas Hermling with Ecofys. And I would like to bind together two of the aspects that were mentioned by Yves-Laurent and by the colleague who was talking about the education.

A building can only be sustainable if it fulfils the needs of its users.

So, I actually don't think that we have completely solved the problem of how to build net zero energy buildings, because we have a very big diversity across the globe obviously, of what it needs to do. And I also totally agree that you said, so **there is no consensus at all about what is a sustainable building**. Actually I think that this term is very inflationary used, "sustainable building", so some people who use wood, they call it sustainable. Others, who have PV on the roof, they already call it sustainably. And I think this is a bit too less to really call it sustainable, because I think what is in the chore is actually what Yves-Laurent said. That a building will never be sustainably when it doesn't fulfill the needs of the people who live in this building. So as long as this is not the case, I think you cannot call it sustainable.

And so, I am very much in favor of really binding together these things. Back to the original **definition of sustainability**, that said we have to **fulfill the needs within environmental limits**. And so, yeah first of all we need to fulfill the needs of the people in the buildings, but unfortunately, and this is then the challenge for the architects, this has to happen within the environmental limits. Thank you.

Elizabeth W. Chege:

Thank you for that.

Man 5 from the audience:

Thank you very much. (speaks in French)

(Applause)

Elizabeth W. Chege:

Thank you for that.

I guess the translation ended after. So, to summarize, a lot of it is asking us to collaborate. And though we are referencing the architect, but it's not just the architect's point of view or work to get the net zero building, it's also the town-planners, because when the architects get down to do their design, they already have a plan that's set and they have the orientation of the town set already. So when they are looking at the facades and how the work with the passive design and the environment, **we need to bring the town-planners, the policy makers, engineers, and** you mentioned it, **the users of the building** as well.

So I hope, I summarized the French well enough, thank you. Thank you.

So I know, we have one minute, so it will allow for one comment. And a parting short from the group. So we'll start with the professor here as we walk across. Thank you.

Brian Dean:

So I think from the IEA perspective, you know we see, it really is personal, it is about the people. It's about **personal comfort** and getting towards that net zero. We need to cycle together a series of policies, that will enable shifting of investment from-, really investments that are harmful to us, you know fossil fuels subsidies and what not, shifting that investment into energy efficiency in buildings. And that will enable at least net zero carbon buildings quite easily. And hopefully enabling something towards net zero energy in the long term.

Ina de Visser:

Thank you. I think the definition of what is an efficient building is still an important one. Even though there is not one answer, we see that in working in so many countries, we have different climates et cetera. There is not one answer. But there is definitely **a risk that some people will define it not ambitious enough**, and I think Ecofys has formulated that well. We should remember that we hope, that these buildings we build now will be used in a comfortable way for many years to come. There is a lock ineffective. You build something and you put solar heating on the roof and you say it's an efficient building, that is waste. So we need to increase that ambition level. Not only in Europe, but definitely also abroad. And that is something where we cannot make it ourselves too easy, because that for the next forty years, that building will be only semi-efficient. Thank you.

Some definitions of a sustainable building might not be ambitious enough.

Elizabeth Beardsley:

Thank you. So I agree, we need to have to work together towards the plaint where all buildings are net zero and sustainable and green and provide a healthy environment for their occupants. Now would really be the long-term goal. I think coming out of the Global Alliance recommendations and our discussion today, what's really needed is to take that step and **connect the building sector in each country with the national NDCs** and to show that there are tenderable things, whether it is connecting with universities and developing the curriculum that's needed, so they have the work force. Whether it's providing more leadership in public buildings. Whether it's unlocking finance. But I think that **bringing together the private sector, building contactors**-, they will all be in cities, to come meet with the national representatives, that is the way to find the right path to net zero.

Yves-Laurent Sapoval:

(speaks French) To give you four numbers-, I'll make my only translation. (speaks French) (laughs) This was only for the French speaking people. So, for numbers: (speaks French) Thirty percent of energy, (speaks French) a city of 1.2 million inhabitants built each week in the world now and for several decades, (speaks French) real estate is one half, is 50 % of global wealth, okay? (speaks French) We spend more than 90 % of our time in buildings. (speaks French) I would say the only thing we have to say today is to make the building's question as important as it's already now.

Martina Otto:

I will forgoe my option to talk, because we are super late and I have a session I am moderating it and I have to run on time, because I am in a panel afterwards. (laughs)

Elizabeth W. Chege:

Okay, thank you very much Martina. Thank you all for coming to this session.

(Applause)