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# Achieving carbon neutrality in Germany by 2050

## Leveraging an explorative system dynamics modelling approach to determine suitable policy options for the German energy transition in the sectors housing and personal transportation

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by

Ingo Schönwandt

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Associated code, models and data are available at:

`https://github.com/ingoswdt/SDEnergyTransitionGermany`

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# 1 Introduction: Facing the energy transition with simulation modelling

The earth is in turmoil, societies and ecosystems alike are facing various threats that may or may not be interlinked and share similar root causes. Aside from persisting disputes over dominions, resources, and religious conviction, climate change is one of the international grand challenges of today. Global temperature rise is responsible for local draughts causing famine and insecurity, leading to further conflict and increased emigration in affected regions (Lustgarten, 2020; McCormick, 2018). Simultaneously, coastal regions and island states face the threat from rising sea levels resulting from the expansion of the earth's water bodies, as the volume of water molecules increases with temperature, and the melting of glaciers and the land-based ice shield in the polar regions (Carrington, 2017, 2020; Quaile, 2012). The UN Refugee Agency[1] counted about 79,5 million refugees in 2019. Of these about 8 million people moved due to climate change in 2019 (Lustgarten, 2020), which the latest Groundswell report by the World Bank estimates could become over 140 million by 2050 (Rigaud et al., 2018). In consequence, many fear that vast areas of the earth could become uninhabitable before the year 2100 and future generations would greatly have to suffer should the temperature trend continue unhalted, including huge losses of flora and fauna around the globe that form habitats to a vast number of species and together guarantee our life on earth (McCormick, 2018; Rigaud et al., 2018). Such a future must be prevented and one critical corner stone in this conquest is the energy transition of our society. But how to best evaluate which policies are best suited to achieve change as profound and complex as the energy transition?

This master thesis presents a deep-dive into the complexity of political decision making in the context of the energy transition as a climate protection mitigation approach by applying simulation modelling and quantitative methods. This work focuses specifically on the climate protection strategy chosen by the German government following its sectoral scope, in order to better understand the policies' potential network effects in between the sectors and the role of society in executing the German energy transition strategy. While already keeping the geographical focus in mind, the following sections will delimit the specific positioning of this thesis and give an overview over the research structure. The first section with more detail discusses the problem posed by climate change and the challenge of the energy transition as a means to fight climate change. Subsequently, suitable research approaches, and depicting the case of Germany as the scope of this study (1.1). This problem formulation is used to highlight the research gap in section two (1.2). On this basis the main research question and its four sub-questions are developed (1.3) that serve to structure this research. Furthermore, the research flow presents a detailed and visual outline of this research (1.4). Finally, this introductory chapter will be concluded to hand over to the literature review (1.5).

## 1.1 Problem definition

This section sets off with a brief outline of the severity of climate change and need for an energy transition, while paying special attention the aspects that define the inherent dilemma of the matter (section 1.1.1). This part concludes with a summary on the complexity and uncertainty of the energy transition. Subsequently, systems thinking is introduced in combination with modelling and simulation techniques as a suitable strategy for structuring the challenge of the energy transition and thus mitigating the problem of complexity (section 1.1.2). Additionally, the concepts of robust and adaptive policy-making are introduced as an opportunity to approach the uncertainty in political

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[1] https://www.unhcr.org/refugee-statistics/

decision making. Finally, the case study is introduced by outlining the properties and status quo of the German energy transition (section 1.1.3). Hence the subsequent section will define the research gap.

### 1.1.1 The Grand Challenge of the Energy Transition

Scientists and institutions agree that climate change is to a large extent caused by our global society and gives evidence to what some call "the Anthropocene", expressing that human behavior has begun to dominate the natural cycles of the earth's systems (Lenton, 2016; Nordhaus, Shellenberger, & Blomqvist, 2012; van Sluisveld and Harmsen et al., 2018). Excessive greenhouse gas (GHG) emissions through the burning of fossil fuels from human societies thereby change the composition of the gas that constitutes the earth's atmosphere, which leads to a greenhouse-like warming effect on our planet (Watts, 2019). Researchers, governments and international organizations agree that GHG emissions have to be limited to net zero as soon as possible but the latest by 2050 in order to keep the planet's surface temperature increase below 2°C and prevent irreversible effects. The major sources of GHG emissions are fossil energy resources such as coal, oil and natural gas that are burned in societal processes. By far the largest amount of human-made GHG emissions is emitted from energy conversion processes in various sectors. The transportation sector requires oil derivatives to power combustion engines and turbines, citizens fire their homes with fossil fuel for heating rooms and drinking water or use fossil sources for cooking, similarly the commercial and services sector as well as the industry sector use fossil fuels for heating, and the energy sector burns fossil fuels to power generators and produce electricity. Collectively adapting society and technologies to a different energy use behavior free of GHG emissions is the ultimate goal of the "energy transition".

Fossil fuels present a cheap and highly potent energy source, easily stored and transported, available and accessible in large quantities, and thus suitable to fulfil the energy hunger of developing and developed countries alike. They were once the enablers and drivers in the industrial revolution, a milestone for mankind, and are still today the foundation of wealth for many countries. Despite readily available alternative energy sources, fossil fuels remain nigh indispensable for our society. At least since the 1980s, however, they have been known to hold the potential for our own demise (Franta, 2018; Climate Files a; Climate Files b). Yet the dilemma of climate change is even more profound.

#### Pointing towards a state of uncertainty

Climate change is an international grand challenge just the same as a large number of people living under inhumane conditions, facing poverty, hunger and inequality among others. These problems are incorporated in the 17 sustainable development goals (SDGs) defined by the UNFCCC as an agenda to achieve and ensure dignified living conditions and equal opportunities for future generations[2]. Additionally, small island states and less developed countries, many of which are located in warmer climate areas, are those expected to be affected first and strongest by climate change impacts. At the same time, corresponding to their level of development and economic output, these societies tend to contribute the least to the climate change problem and thus have little influence on making a change. On top of GHG emissions accelerating the atmospherical green house effect, also other interferences in other spheres of the earth are affecting the climate change, such as deforestation, impact on the soil from intensive agriculture, and a change in the earth's albedo effect due to diminishing bright reflective ice and snow surfaces around the globe (United Nations, 2018). Following the technological development and globalization, all these factors became deeply intertwined with the human society. Considering the importance of fossil fuels for countries' economies and technological development

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[2] https://sdgs.un.org/goals

as well as peoples' prosperity in the face of the aforementioned poverty and hunger, climate change brings us in a quandary and state of great uncertainty: both action and inaction to reduce GHG emissions pose a potential threat to societies.

### An argument for energy transition

Nonetheless, since, despite brave efforts by Climeworks[3] (Tsanova, 2020) and others[4], there is little hope for industrial plants to absorb GHG emissions from the atmosphere equal to the amounts that they are being emitted or feasible solutions that capture GHG emissions right at their source[5], there is no way around the energy transition as a means to fight climate change (Rueter, 2014). Thus the use of fossil fuels in the aforementioned sectors needs to be replaced by other energy carriers. For many applications electricity is considered a valid and feasible alternative as it is a versatile form of energy and is already in wide use. Additionally, electricity can easily be generated with environmentally friendly technologies from renewable energy sources like the wind and solar radiation. However its properties require different handling and infrastructure compared to fossil fuels, such as a form of battery or electricity grid (power lines). Even though renewable energy sources are abundant and basically accessible everywhere around the globe, the energy content that can be captured from wind and solar radiation per square meter is limited and not scalable as compared to fossil fuel mining and drilling sites and fossil fuel power plants. Thus the infrastructure requirements for the use of electricity are significantly higher and the electricity production capacity is dependent on the dedicated surface area, which are the main points of criticism in the energy transition, not considering the specific technical challenges regarding electricity balance and grid stability. To overcome these shortcomings, a lot of research is being done to find suitable intermediate energy carriers to facilitate the storage and transportation of electricity, such as hydrogen and sustainably produced methane, however, so far to no avail for large-scale rollouts ("Power-to-Gas", n.d.). Additionally, the energy transition is also a call to drastically increase energy efficiency throughout society. First, this can directly reduce GHG emissions simply from less energy demand. Second, this also aims to mitigate the mismatch between replacing potent fossil power plants with space-intensive renewable power plants and increasing the demand for electricity by connecting also the energy intensive processes to the electricity grid, such as transportation, household heating and industrial process heat. Such undertaking obviously entails profound infrastructure changes as well as adapting different habits in handling and conserving energy in our society.

### A state of paralysis

The political track record on executing the energy transition> As stated above, the double-edged aspects of fossil energy resources and their connection to climate change have been uncovered about 40 years ago. In the year 1992 the United Nations Framework Convention on Climate Change (UNFCCC) was formed to mark the initiation of a unified attempt of the world's countries to take action against climate change by means of an energy transition. However, the lack of will, generous targets and loose regulations, and a strong opposition produced poor results and so global GHG emissions continued to grow, along with the problem of climate change. In 2015 the matter became pressing enough so that a total of 197 UN member states signed the so-called Paris Agreement (further also referred to as 'the Paris goals'), acknowledging the urgency of and committing to significantly reducing GHG emissions by 2050, leaving the development specific strategies to the states (Crippa et al., 2019; IPCC, 2018; United Nations, 2015).

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[3] https://www.climeworks.com

[4] https://www.ccsnorway.com

[5] https://www.forbes.com/sites/energyinnovation/2017/05/03/carbon-capture-and-storage-an-expensive-option-for-reducing-u-s-co2-emissions/

Despite the unified demonstration of will in 2015, five years later the struggle to act on the Paris Agreement continues globally as well as nationally and locally. Many leaders are hesitant because a global energy transition could potentially threaten the wealth and development of many countries and individuals. On the one hand, the "multi-level perspective" (MLP) developed by F. W. Geels (2002, 2011) finds confirmation in current events, where incumbents in politics, business and industry are trying hard to defend their position, opposing vital change and stricter regulations, downplaying the risks of climate change compared to economic losses (DeFries et al., 2019; Holden, 2020; Rosenthal, 2018). Many nations have been built and optimized to run on fossil fuels and many others are following, so the vested interests are enormously powerful just as the transition to new technologies can potentially make decades of substantial investments and work obsolete, not to mention that it questions many peoples' habits and ideas of how the world works. On the other hand citizens worldwide are mobilizing and demand action. Civil protests and movements such as 'Fridays for Future', 'Global Climate Strike' and 'Extinction Rebellion' keep fiercely calling to leaders worldwide to increase efforts to reach the climate targets and stop climate change (Farand & Russo, 2019; Pinzler, 2019; Sauer, 2019). As a result, the latest United Nations Climate Action Summit 2019, organized with great care by the UN Secretary General António Guterres, produced a mirror image of the global state of paralysis on this matter. Despite the strong consensus and high risk potential, "around the Summit the question has become: if [alternative] solutions are cheaper, public opinion is mobilized and [adverse] impacts much clearer why is political action not following?", summarizes Mabey (2019), co-founder and CEO of the independent think tank "Third Generation Environmentalism" (E3G).

### Complexity and uncertainty in the energy transition

Needless to say, just as climate change, the energy transition is characterized by high levels of complexity and uncertainty. This extends to the inter-temporality of the problem, including the natural human weakness of making long term choices, and the fact that societies are highly diverse and interconnected. The latter implies great interdependence with citizens' environment and thus societies typically simultaneously benefit and suffer from the properties of their surroundings. The balance of both determines whether they thrive or wither in the short and the long term. In this regard, policy choices face the uncertainty of adequately evaluating the short and long term drivers. In consequence, climate change policies may require short term sacrifices in order to obtain long term gains, which may require decision that demand sacrifices in the short term for the promise of long term gains. However, it is human nature to greatly over-value short term effects to those in the far future. Since climate change is an intergenerational threat that is expected to affect future generations a lot more than today's population, who is the only one able to prevent or mitigate the adverse effects. This compromise is naturally difficult to accept for many people.

Additionally, the problem of complexity implies that the actual effectiveness (a policy's impact) and efficiency (a policy's ratio of intended to unintended effects) of policies are uncertain and difficult to accurately assess beforehand. While citizens' characteristics, beliefs, needs, and preferences are very diverse, their individual behavior and actions are to the most part unpredictable. Yet policies always target collectives of citizens and thus are prone to unjustly affect some individuals, which negatively impacts the outcome of a policy as a whole.

Understanding climate change as an issue of high complexity and uncertainty outlines the extent of the problem at hand. Before going into solution finding, the case of the German energy transition is introduced in the next section, which links the challenge to the real world. This allows to pin-point specific problem areas.

### 1.1.2 Case study: The German energy transition focusing on transportation and housing

Germany is a predestined object of research to explore the challenge presented by the energy transition in well developed and economically strong countries, which are the largest contributors to climate change. The Germany government is a strong advocate of the Paris Agreement and climate action but finds itself caught in the middle of opposing stakeholders just the same as many other countries (Crippa et al., 2019). Furthermore, Germany is among the most developed countries with sophisticated political and social systems, a strong economy with international ties, advanced industries, and a high level of research and development. It is the largest EU-28 member state in many regards, accommodating about 16% of the population, almost 21% of economic output, and accounting for 20% of the GHG emissions, the largest contribution to climate change among the EU-28 countries (EEA, 2018). One could argue for less emissions per capita and economic performance compared to other member states but the European reduction targets to achieve near or net zero GHG emissions by 2050 apply just the same. Despite its economic strength, the country is struggling to achieve its Paris goals and self-set targets, which prompted harsh protests (Germany to fall short of 2020 climate goals: report, 2019; "Große Koalition einigt sich auf Klimaschutzpaket", 2019; "Kanzleramtschef verteidigt CO2-Preis-Pläne", 2019; Pinzler, 2019; Sauer, 2019; The cost of climate inaction, 2018; United Nations, 2018).

**Energy transition ambitions in Germany**

In that regard, the Paris Agreement, similar to most international agreements, suffers from being a merely voluntary pact calling upon the self-responsibility of its signatories. Regardless, the German government has repeatedly demonstrated its determination to achieve its Paris goals by implementing national policies even though the several opposing parties and environmental activists have repeatedly questioned the policies' effectiveness (Bovermann, 2020; Haak, 2020; Helberger, 2019; Záboji, 2019). Being a full member of the European Union (EU), which has implemented the Paris goals in its own policies and has made corresponding legislation, however, partially fills this void and increases the pressure on its member states to meet their targets, as shown by the ensuing law suits pending at the European Court of Justice (ECJ) regarding air pollution infringement of

Table 1.1.2: Emission targets per field of action

| Field of action | 1990 (mio tons of CO2 equivalents) | 2014 (mio tons of CO2 equivalents) | 2030 target (mio tons of CO2 equivalents) | 2030 target (reduction in % compared to 1990) |
|---|---|---|---|---|
| Energy sector | 466 | 358 | 175-183 | 62-61% |
| Building sector | 209 | 119 | 70-72 | 67-66% |
| Transportation sector | 163 | 160 | 95-98 | 42-40% |
| Industry sector | 283 | 181 | 140-143 | 51-49% |
| Agriculture sector | 88 | 72 | 58-61 | 34-31% |
| Others | 39 | 12 | 5 | 87 % |
| Sum | 1248 | 902 | 543-562 | 56-55% |

source: KfW Bank, n.d. b

several member states (European Commission, 2018; Osterath, 2018). Certainly, Germany's federal and democratic foundation also plays a role as it systemically tends to strengthen permanence and slow down change, making radical and urgent projects like the energy transition a specific challenge.

Undeterred by the German government's courageous performances on recent climate conferences, according to the German climate protection report 2018 (BMU, 2019: Klimaschutzbericht 2018), is not meeting its current targets and is thereby also critically endangering meeting its 2030 and even 2050 targets. To date, the German primary energy consumption over all sectors relies over 78,3% on fossil fuels (35,3% oil, 24,9% natural gas, and 17,9% coal derivatives) (AG Energiebilanzen (AGEB), 2020b) with a contribution to final energy consumption from transportation of 30%, households of up to 25%, industry of 29%, and the commerce, trade and services sector of 15% (AG Energiebilanzen (AGEB), 2019b).

Overall there are three milestones from the initiation of the climate protection strategy on the road to achieving a net zero GHG emissions society. The first milestone is hit this year in 2020 with a target of a total GHG emissions reduction of 40% compared to 1990. The second milestone is set for 2030 targeting a reduction of 55% of total emissions compared to 1990. The effort is strategically distributed among the sectors (see table 1).

In 2050 the last milestone marks the German "near zero GHG emissions" target, referring to an 80%-95% emissions reduction with respect to the baseline year. Figure 1 depicts the historic GHG emissions per sector, a total emissions estimate for the year 2020 as well as detailed emissions targets per sector for the year 2030 and a rough trajectory for the year 2050. Two different approaches apply to address the GHG emission targets: (1) use less energy through reduced use of service and/or improved energy efficiency and (2) use energy from sources with less GHG emissions by transitioning to alternative technologies.

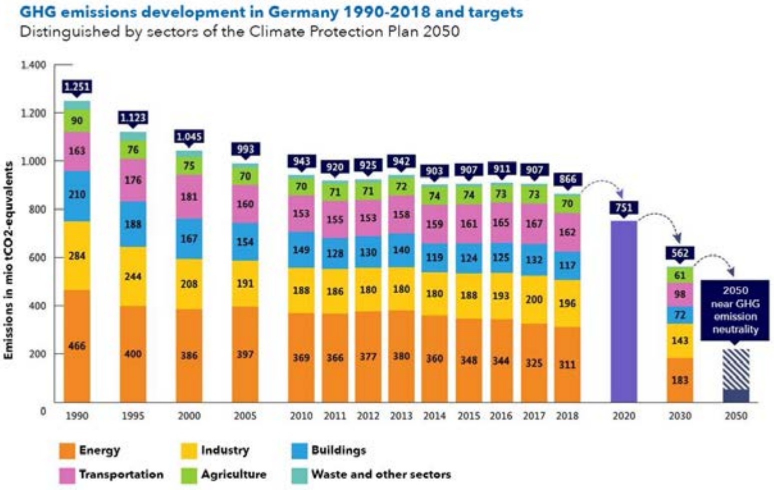

Figure 1.1.2: GHG emissions development in Germany 1990-2018 and targets.
Based on: Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU, 2019b)

## Germany's two problem sectors

However, Germany has two problem sectors in the quest of reducing GHG emissions: "Traffic and Transport" (transportation) and "Building and Living" (housing) (BMU, 2016, 2019e). Compared to 1990 levels, the emissions from transportation remained at about the same levels because while the efficiency of automobiles greatly increased, so did the number and use of cars – a reboundeffect. In contrast, the emissions from the "Building and Living" sector were following a promising trajectory until 2014 when the trend reversed and emissions started to increase again (BMU, 2019: Klimaschutzbericht 2018). Subsequently, the gap towards Germany's 2030 and 2050 climate protection targets for both sectors is larger than planned.

Considering that the macro-trends of increased globalization and technological advances will continue to making it easier and cheaper to travel, it can be assumed that the demand for transportation will stay the same or even increase in the long term. As mentioned before, at the same time the efficiency of existing transportation technologies is already very far developed. Thus a suitable strategy for the transportation sector should focus on a transition to alternative fuels, which can include hybrid or battery electric and (in the medium future) hydrogen vehicles and also other modes of transportation like cycling, public transport and railways, for example.

With regard to the housing sector, the German government opted for a combined approach of reducing energy consumption and switching to more environmentally friendly energy sources (Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU), 2016, 2019e). Until now new standards and technologies in the housing sector found implementation mostly through new constructions. Therefore the energetic quality of the German housing stock is very diverse and similar to the large range of construction year and style, the insulation levels range from nearly none to ultra high-efficiency insulation that allows households to produce more energy than they consume within a year (so-called "energy-plus-houses"). According to the Umweltbundesamt (UBA) (2020), in 2018 households used on average 67,6% of their total energy consumption for heating, over 15,9% for warm water heating, and 16,5% for electricity (not considering energy for motor vehicles). The main sources of heating in Germany are natural gas (45%) and heating oil (20%) (Statistisches Bundesamt, 2018). Key measures for the energy transition in the housing sector therefore are insulation improvements to reduce the heating energy consumption, solar thermal and photo voltaic add-on installations as renewable sources of energy, turning households into so-called prosumers and reducing their energy demand from external sources, and replacing old fossil heating systems, especially those based on heating oil (BMU, 2016, 2019e; BMWi, 2015, 2019a, 2019b, 2019c).

At the same time, the energy sector is undergoing a series of significant changes. First, the last nuclear-fired power plants are set to phase-out by the end of 2022 as a consequence of the 2011 Fukushima incident (Presse- und Informationsamt der Bundesregierung, 2011). Second, as a measure to reduce GHG emissions the German government recently sealed the phase-out of coal-fired power plants the latest by 2038 with the option of an early phase-out in 2035 (Presse- und Informationsamt der Bundesregierung, 2020). Fortunately, the electricity production capacity from off-shore wind power shall be expanded drastically in order to reach four times its current capacity by the year 2030 (Deutscher Bundesrat, 2020a). Recent discussions also demanded appropriate adjustments of regulations and support relating to on-shore wind and solar energy (Deutscher Bundesrat, 2020a). The overarching question is if the capacity falling away from fossil power plants can be replaced in time to meet the electricity demand, not even considering technical challenges regarding electricity grid stability (Enkhardt, 2017).

As previously discussed, the production factors of finance, natural resources and labor force also play a significant role in the energy transition. The available budget of households in combination with governmental subsidies in Germany set natural limits in the factor endowment just as limitations presented by maximum extraction and production capacities for natural resources and products and the maximum available labor force to execute the required changes and maintain future infrastructure. So far the German government is specifically applying monetary incentives to stimulate households to make efficiency improvements and buy more electric vehicles. Such demand-side policies strengthen the market-pull effect, hoping that supply of materials, products, and workers follows suit.

In summary, the German government is simultaneously applying supply- and demand-side measures in order to master the energy transition. Critics of the current strategy are very concerned with the balance of energy supply and demand. Not only are major electricity capacities planned for phase-out in the near future while the construction of volatile wind and solar power plants have kept a slow pace. The government also pursues the goal to convert significant amounts of personal individual transportation from fossil fuel to electricity powered automobiles, as outlined in the Klimaschutzplan 2050 (BMU, 2016, 209d). Thus the German strategy takes into consideration that a temporary reduction in electricity supply may be accompanied by a potential increase in electricity demand. The consumer-side  transition efforts are supported by various financial aid schemes by the German government. However, can financial incentives as demand-side measures be effective enough to achieve the energy transition goals? Subsequently, this research is not solely about the balance between supply and demand, also the influence of finance, workforce, and consumers' choices play a critical role. The energy transition is a social challenge and therefore multiple times more complex than "maintaining the balance". These circumstances are only adding to the already high difficulty of the matter, underlining the question: "How promising is the current strategy to achieve net zero emissions in the transportation and housing sectors by 2050 in Germany and what else needs to be done?"

With these concepts and features in mind, a number of approaches become apparent as an opportunity to tackle the German energy transition as a contribution to climate change mitigation.

### 1.1.3 Opportunities: systems thinking, simulation modelling, robust and adaptive policy-making

Of course there is not one simple answer to this complex problem, as is the nature of societal challenges such as climate change and the energy transition. Li, Trutnevyte and Strachan (2015) summarize that "any transition of today's energy system to a state with dramatically lower greenhouse gas emissions is not only a technical matter. The behavior, values and strategies of individual actors as well as policies, regulations and markets also shape energy system transitions. Understanding how such socio-technical energy transitions might be brought about is a major interdisciplinary research challenge." (p.290). Li, Trutnevyte and Strachan (2015) highlight the embeddedness and interdependence of the use of energy in today's society, stressing that the endeavour to pursue radical change of a society's energy consumption behavior may on the one hand also be dependent on properties not directly related to and on the other simultaneously have an affect on societal spheres not directly linked to the energy consumption itself. These complexity characteristics make political decision making towards a GHG emissions-free society particularly challenging because the total range of effects is difficult to assess. However, several approaches can be combined to reduce said complexity. Breaking down the problem into a set of sub-systems and applying simulation models in order to explore their behavior and develop robust policy strategies can bridge this gap.

#### Systems of the energy transition

Similar to a large machine with many components as sub-systems, also society can be conceptualized with a systems approach and perceived as many interconnected sub-systems. With regard to the energy transition problem, it is expedient to distinguish the sub-systems based on the use-cases and technologies of energy consumption because these shall be efficiently targeted. Accordingly the German Federal Ministry for Economic Affairs and Energy  (BMWi) distinguishes the final energy consumption in five sub-systems:

- **Housing and living** (by form and purpose of energy use): Living space heating, Warm water heating, Process energy (cooking, cooling, washing, electric appliances), and Lighting
- **Transportation** (by type of propulsion technology): for each personal and cargo transportation: over land (road-based, rail-based), on water, air
- **Industry** (by form and purpose of energy use): Mining & drilling, Processing, Finishing
- **Trade, commerce and services** (by form and purpose of energy use): Process energy, Space heating, Power for ICT components
- **Energy sector** (by energy resource and conversion technology): Coal, Gas, Oil, Nuclear, Hydro power (flow turbines, dams, pumped storage), Wind (on-shore, off-shore), Solar (thermic, photo voltaic), Biomass (Wood, Pallets, Waste, etc)

As depicted in the case study outline, the this research specifically focuses on the housing and transportation sectors in combination with the energy sector.

Additionally, Li, Trutnevyte and Strachan (2015) highlight the necessity in taking an interdisciplinary research approach because the energy transition is deeply anchored in society. Cherp, Vinichenko, Jewell, Brutschin, & Sovacool (2018) criticize that simple techno-economic perspectives have difficulties accounting for aspects of system inertia, technological innovation, multiple actors and path dependence, often assuming policies to be external normative targets. Therefore Cherp et al. (2018) propose to broadening the approach by including socio-technical and political perspectives. Which societal aspects would thus be relevant to the energy transition?

Economic theory has produced various methods of looking at transformation in society. The idea of the production-possibility curve (PPC) is very versatile and can be applied to individuals and collectives alike in order to portray that actors have options between either the consumption of different goods, the investment in different sectors, the production of different products and many more. Furthermore, the concept of factor endowment in economics commonly describes the how well a country is equipped in terms of capital, labor, and land, whereby land refers to the area of land as well as access to natural resources, agriculture and forestry. As a result the core societal systems involved in the energy transition include available capital, natural resources and the labor force, where instead of "natural resources" in this case "raw materials" and "finished products" are better linked to the energy transition. Consequently, analyzing the German energy transition must take into account the financial endowment of households in combination with governmental support schemes, the production capacity of the required materials and products as well as the available labor force to undertake efficiency improvements and make the change happen. Subsequently, this systems approach can be operationalized using computer-based modelling techniques.

### Simulation models

As an interdisciplinary policy challenge numerous policies will have to address many different issues to achieve the energy transition, while every aspect about it is plagued with uncertainty (Lempert, Popper, & Bankes, 2003). Policymakers therefore apply various tools in order to further reduce this complexity and mitigate the lack of comprehensive understanding.

Next to information gathering, debating, campaigning for advocacy coalitions and negotiations, models collectively called 'integrated assessment models' (IAMs) are essential instruments in the creation of policies such as the guiding EU Energy Roadmap 2050 (EC COM, 2011) or the German

"Climate Protection Plan 2050" (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU), 2016) together with its various addendums as well as other policies (Schwanitz, 2013). Whereas information gathering and making commitments in negotiations only add to the problem of complexity in the political decision making process, by applying systems thinking models are vital in structuring the policy problem, making it tangible and thereby reducing its complexity. With the help of links and formulas, models establish relationships between the gathered facts, actors, targets, and resources, which enables assumptions about the collective behavior and impacts of policies. In combination with advanced analysis methods simulation models allow to explore, assess and refine the properties of envisioned policies in safe environments. Models are therefore essential tools not only in policy making but also in other disciplines, such as economics, engineering, and the natural sciences.

### Exploratory modelling and analysis

It is impossible to evaluate policies by predicting their outcomes and effects using simulation models, due to the inherent uncertainty they would not yield useful information. Nonetheless, Pfenninger (2014) and Verburg (2016) argue that simulation models are well suited to highlight potential challenges and uncertainties. Furthermore, scholars suggest to incorporate exploratory modelling and robust optimization analysis approaches in order to deal with the problems of complexity and uncertainty (Bankes, 1993; Kwakkel and Pruyt, 2013). The Exploratory Modelling and Analysis method (EMA) was explicitly developed to overcome the high level of uncertainty in complex policy problems by exploring the full range of available scenarios. Furthermore, Lempert, Groves, Popper, and Bankes (2006) recommend to evaluate policies by their robustness. Translated for the energy transition, a robust policy would perform better over a variety of scenarios in achieving GHG emission targets while at the same time keeping the balance between energy demand and supply and minimizing the burden for society, for example in terms of cumulated costs. Therefore the approach leverages what is known for certain in order to determine which measures could best achieve and maintain desired states. Even though the future will remain a mystery, choosing the most robust strategy represents 'the best we can do' considering the expected gains and sacrifices.

## 1.2 Research Gap

In consequence there are several research challenges concerning modelling the energy transition in Germany as well as finding a suitable policy strategy to fulfil Germany's climate protection targets. Overall this research pursues the question about how Germany's GHG emissions can be reduced to net zero by 2050 because this is the objective of the energy transition. Numerous problem areas could be identified that present potential drivers and hurdles in the energy transition and need to be better understood. At the same time, grasping the energy transition as social challenge unavoidably also presents a modelling challenge as things become less quantifiable and relationships more obscure.

In the case of the German energy transition, governing the transportation, housing, and energy sectors has shown to face the greatest challenge. The German government is determined to tackle these sectors with a high priority and thus set the focus of this research. Furthermore, it appears adequate to limit the "transportation sector" further to consider only personal transportation that has a direct link to household behavior, goods transport will be excluded from analysis.

In the open-market economy, the energy transition stands to succeed or fail with the societal participation and capabilities. Therefore, finding adequate policies demands to equally account for financial capabilities, available resources and products, and the labor force aside from the core energy transition sectors. Additionally, the problem that the energy transition is embedded into a complex social system is further stressed by the uncertainty of citizens' behavior as a reaction to policies.

Furthermore, simulation modelling was proposed to systematically capture the problem of the German energy transition and enable quantitative analysis methods. Integrating the technical and societal dimensions to achieve a reduction on the environmental dimension presents the core challenge in modelling the energy transition. The key societal aspects to consider the financial capabilities, materials and products, the labor force, and mechanisms of making consumption choices. Each of the aspects potentially opens up complex new dimensions so that the boundaries must be set carefully.

Even though such analysis only really thrives under an encompassing system-wide approach, unfortunately this thesis can only handle a very narrow scope that is limited to a limited number of sectors in an isolated geographical sphere. Therefore, the results of this research will inevitably disregard any, potentially significant, interaction with other countries as well as other sectors within the country of investigation, which presents a major flaw in this undertaking but cannot be avoided.

Finally, specific approaches are well suited to leverage the simulation model for evaluating the policy options and determine a robust strategy. This will allow to answer the main research question:

**"What could a suitable set of policy measures look like to achieve net zero GHG emissions by 2050 in the sectors housing and personal transportation as part of the German energy transition?"**

## 1.3 Research Approach

The identified research gap addresses a number of specific problems, which are formulated into XX (enter number of SQ) sub-questions (SQ) below. Answering each SQ shall enable new insights for practitioners in model-based decision-making approaches as well as policy-makers on the energy transition in Germany.

In order to begin with designing the simulation model, more scoping is necessary to fully understand the approach the German government is taking, which serves as a good starting point. This step requires a thorough examination of the communiqués and decisions the German government published on its various websites. As policies are constantly evolving, all publications until 01 July 2020 will be considered. The investigation aims to capture both the direct policies on the energy system as well as indirect measures that take the societal approach:

**SQ1: What are the direct and indirect policy measures the German government is taking at present to achieve the energy transition targets in the focal sectors?**

This review holds two vital insights for the next steps. First, it reveals a collection of specific measures aiming for an energy transition in the German context, which are immediately relevant to include in the model. Clustering the measures by sector and topic may facilitate to identify the relevant societal mechanisms to include in the model. As discussed an interdisciplinary on the energy transition is recommended. The review insights are subsequently combined with the common concept of factor endowment from economic theory in order to understand societal drivers and dependencies in the context of the energy transition. Additionally, Verburg et al. (2016) claims that modelling outcomes are often restricted by high levels of aggregation. Next to refining core principles of modelling the energy transition, also the modelling detail shall be expanded to capture regional properties. The specific data availability is a key driver of the final model resolution. With regard to transition modelling, it seems especially insightful to opt for high resolution modelling in order better understand the dynamics of the transition processes.

The modelling process takes place in multiple steps and is an iterative process of repetitive modelling and testing. Moreover, whenever data availability and quality is uncertain it is common practice to first scout for data points and then develop the model structure based on the data that can be found, so-called data-informed modelling practice. Following this approach, the next research question focuses on developing a comprehensive model representation of the German energy transition:

**SQ2: How can a simulation model on the energy transition in the German housing, transportation, and energy sectors adequately represent the technical, societal, and economic mechanisms?**

Several steps are implied in this question:

- How can the existing system of energy consumption in the focal sectors in Germany be conceptualized while also including the societal factors that govern the development of the society and its energy consumption over time?
- Which data is available to fuel and calibrate a model for this task?
- How to best transform this concept of the energy transition into a comprehensive simulation model and where to set the research time frame?
- Which input variables and dependencies present potential uncertainties that need to be considered in the German energy transition?
- Where, at which variables, do current and potential policies in the German energy transition connect to the simulation model?

Based on these findings, the model will be developed. Keping in mind that there is no perfect model to represent the real world, the previous considerations are supposed to facilitate the development of a good model for the purpose in answering the main research question.

So the main research question is determined to find suitable sets of policies. The next subquestion is aimed to qualify 'suitable sets of policies' by answering:

**SQ3: Which evaluation approach can help to determine a suitable set of policies in combination with the quantitative modelling approach?**

Based on the three perparatory steps, we can approach the final two research questions. First of all, the current set of policies is targeted for scrutiny. Several doubts have been raised regarding the existing policy measures, which will be used as a starting point. Arguments were made whether the simultaneous phase-out of major electricity capacity and the push for significantly increasing the share of electric vehicles could bring the electricity sector into trouble. Additionally, the potentially limiting factor of resources in its broader sense was discussed. So the fourth subquestionis:

**SQ4: To what extend are the given policy measures in the focal sectors promising to achieve the energy transition targets in Germany?**

It will be accompanied by two supporting questions:

- Could the transition to purely electric vehicles threaten to push the cumulated electricity demand significantly over available electricity supply capacities while complying with designated phase-out plans in the energy sector?
- Could the household budgets, the workforce, and other resources play a limiting role in achieving Germany's energy transition targets in the focal sectors?

Subsequently shifting the gaze to the future, we need to understand the drivers of the system in order to find a suitable set of policies to achieve the energy transition:

**SQ4: What could be the strongest limiting external factors and the most enabling policy measures in the energy transition between the three focal sectors?**

In that regard, since the pricing of GHG emissions by levying a CO2 tax was fiercely debated. There is specific interest in analyzing the potential of CO2 pricing as a policy lever for achieving the German energy transition targets in the focal sectors. Concluding these four subquestions, hopefully the main research question can be presented with a clear strategy:

**"What could a suitable set of policy measures look like to achieve net zero GHG emissions by 2050 in the sectors housing and personal transportation as part of the German energy transition?"**

Following these research questions, this work's contribution is two-fold. First it aims to contribute to the knowledge base on energy transition data and specifications by an extensive review of data sources in the fields of housing and personal transportation and creating a comprehensive database. Second, this research seeks to add to the existing knowledge pool on the German energy transition by examining potential external effects and explore possible policy adjustments. Additionally, this research also tries to assume a more societal perspective on the energy transition, which may be of interest to the modelling and simulation community. It is an attempt to integrate system components from the spheres of society, technology, and economy.

# 2 Research context

This chapter contains 4 sections addressing two aspects of this research. The first part attends to the energy transition case of Germany. As the status quo of the problem at hand is already captured well in the previous chapter (section 1.1.2), the first section jumps right into the specific energy transition policy strategy of the German government and the targets it has set itself to achieve the energy transition by 2050 (section 2.1). Following, the policy dimensions of the German energy transition case are discussed with a focus on the implications these dimensions signify for the modelling process (section 2.2). Finally this leads to the system boundary definition (2.3). The second part is concerned with presenting a suitable method for political decision making under deep uncertainty as in the case of the energy transition (section 2.4). Hereto, first the problem of uncertainty inherent to political decision making is discussed (section 2.4.1), for which robust decision making is introduced as a suitable concept (2.4.2), resulting in the final modelling and evaluation approach (section 2.4.3).

## 2.1 German energy transition policy strategy

The German energy transition strategy was conceived in multiple steps. Due to its long timeframe it combines long-term goals with short-term measures and intermediate re-adjustment stages. The overall strategy is anchored in the Climate Protection Plan 2050 (CPP2050), which recognizes the international context of climate action and outlines the German climate protection approach (Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU), 2016). The CPP2050 is further accompanied by intermediate climate action programs that set the detailed targets and measures for short to medium-term milestones. Each of those programs is then executed with a series of acts and decrees. In this case, the CPP2050 in combination with the Climate Protection Program 2030 (CPP2030) is guiding the German energy transition and all relating political debates (Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU), 2019e). The full collection of energy transition policies outlined in the CPP2030 can be found in Appendix A. The relevant policy actions are summarized by focal sectors in the table 2.1, giving numbered references to the full table found in Appendix A, which also includes the assumed direct and indirect effects as well as the respective component or mechanism to include in an energy transition model.

First of all, as a result of various negotiations in preparation of the UN Paris Climate Conference 2015, the EU launched an emissions trading system (EU-ETS) on GHG emissions for the energy sector and a majority of the industrial sector in Europe (Bundesministerium für Umwelt Naturschutz Bau und Reaktorsicherheit (BMUB), 2014). Following an open-market approach, the EU-ETS was supposed to impose a price on and thereby lead to the reduction of GHG emissions in Europe, which are measured by their warming effect equal to that of the respective amount of CO2 emissions (tCO2equ). However, its effectiveness was strongly criticized as the instruments suffers from an ongoing oversupply of certificates since its introduction, keeping the price per ton of CO2 equivalents well below effective levels even though the number of certificates issued was constantly reduced.

Subsequently, with the CPP2030 the German government begins with a series of overarching measures addressing GHG emissions and the affordability of measures for households and businesses. Thereby the government recognizes the importance of consistent and effective GHG emissions pricing to internalize their effects (measures #1-3). This calls for a model implementation that represents a GHG emissions price mechanism that is linked to fossil fuel consumption in households, transportation, and electricity production. The price mechanism is governed extrinsically due to the limited scope

Table 2.1: Germany’s energy transition policies in the focal sectors

| # | **GHG emissions** | # | **building sector** |
|---|---|---|---|
| 1 | CO2 pricing relating to heating and transportation | 17 | tax relief program for energetic renovation of buildings |
| 2 | ETS as instrument in sectors heat and transportation | 18 | financial support program for efficient buildings including replacement bonus for oil heating |
| 3 | minimum price in ETS | 24 | new constructions energy standard by GEG2020 |
|  |  | 25 | renewal of GEG in 2024 |
| # | **relief of citizens and economy** |  |  |
| 4 | reduce electricity costs | # | **transportation sector** |
| 5 | increase fixed-rate allowance for long distance commuters | 29 | increase utility of rail passenger traffic |
|  |  | 30 | increase utility of public transport |
| # | **energy sector** | 31 | expansion of cycle-tracks, bike parking space, and improving framework conditions |
| 8 | stepwise reduction until termination of coal-power in 2038 | 32 | development of electricity-based fuels (alternative fuels) |
| 9 | expansion of renewable energy to 65% share of the gross electricity consumption by 2030 | 33 | supporting advanced bio-fuels (alternative fuels) |
| 10 | development and modernizing of CHP plants | 36 | increase low-CO2 passenger cars on roads |
| 11 | convert heat-grids to renewable energy and unavoidable waste heat | 39 | expansion of refueling, charging and overhead wiring infrastructure |
| 16 | investment program: energy efficiency and process heat from renewable energy in the economy | 40 | automating, connecting, liquifying traffic. enable innovative modes of transport |
|  |  | 41 | tax relief program for electric vehicles |

source: Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU). (2019e). Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050.

of the model but could be influenced by the share of fossil fuels of total energy consumption. It must also be inline with politically set lower and upper bounds of 25-55 EUR/tCO2equ and 65 EUR/tCO2equ respectively according to the decision of the Bundesministerium für Wirtschaft und Energie (BMWi) (2020).

Additionally, policy makers attempt to relieve consumers of fears that potential steep energy price increases could threaten their existence by granting various subsidies (measures #4 and #5), thus the model must avoid rapid significant price changes.

### 2.1.1 Energy transition: Energy

The energy sector in Germany is meant to transition from coal and nuclear power based electricity production to wind and solar energy while the consumption of fossil fuels in the transport sector is also reduced and replaced by electricity of alternative energy carriers. First, it is undergoing a phase-out of nuclear energy by 2022 brought about by the Fukushima incident in March 2011 (Presse- und Informationsamt der Bundesregierung, 2011). Nuclear energy sources produced 1178 PJ of electricity, equal to 22,7% of the country's electricity production in 2011 (AGEB_auswertungstabellen_2018) and amounted to 829 PJ and 17,8% of electricity contribution in 2018 according to the AGEB (2019). Therefore the remaining reduction amount until 2022 may still be significant.

Second, the urgency of climate protection strategies forced the government to also set a phase-out date for coal-fired power plants, which was decided upon in July 2020 (Presse- und Informationsamt der Bundesregierung, 2020). Electricity production from hard coal and lignite sources will therefore be abolished in a step-wise process by 2038 with the option to move out of coal derivatives already by 2035 if possible (measure #8) (Presse- und Informationsamt der Bundesregierung, 2020). In 1990 about 3066 PJ (56,7%) of energy from coal derivatives was used for electricity production, which reduced to 2673 (50,9%) in 2018 according to AGEB (2019). This is a significant amount, which requires an adequate replacement strategy.

Third, the CPP2030 therefore sets the intermediate goal to simultaneously raise the contribution of renewable energy to 65% share of electricity consumption by 2030 (measure #9). Thus a transition model should account for the synchronous reduction of coal and nuclear power and increase of renewable energies like wind and solar power. In this regard, the Federal Council of Germany passed an addendum to the wind on sea act (WindSeeG) to increase offshore wind energy capacity by 2030 (Deutscher Bundesrat, 2020a and 2020b). Additionally, the German Federal Council recognizes further need to support the expansion of solar parks for electricity production (Deutscher Bundesrat, 2020a).

Fourth, the energy transition shall be backed up by efficient use of fossil energy. The CPP2030 aims to further improve and develop combined heat and power plants, which mainly applies to gas fired power plants. Additionally, some amount of waste heat in industrial processes is unavoidable. The energy transition should specifically target to capture and direct this unavoidable heat energy emissions to district heating grids according to the CPP2030. (measures #10, #11)

In summary, the energy sector is planned to phase-out over 68% of its nuclear and fossil-based electricity production by 2018 standards and to replace that capacity with renewable sources by 2038.

### 2.1.2 Energy transition: Housing

Shifting the view on the housing sector, the CPP2030 aims to leverage incentives for households to take an active part in the energy transition by becoming so-called "prosumers", consumers who participate in the energy production. The efforts in the housing sector are mostly anchored in the motion of the new "Gebäudeenergiegesetz" (GEG) conceived by the Bundesministerium für Wirtschaft und Energie (BMWi) (2019a). First, this strategy implies a ban on oil and coal based heating systems in newly constructed homes in combination with strict regulations of replacing old heating systems (measure #18). Thus, eventually oil and coal heating systems are also phasing-out. Simultaneously, the GEG implements new energy efficiency standards for new buildings that are at about 37% lower than the current average energy consumption of households (measure #24) (BMWi, 2019a). The CPP2030 further suggests that the GEG should experience an overhaul in 2023 with respect to the energy standards for buildings as required by European law (measure #25) (BMU, 2019e). This could imply further lowering the characteristic energy consumption value for new buildings. In

Table 2.1.2: Government subsidies on building energy improvements

| **Energy standard after renovation** | **Financial benefit share** | **Financial benefit amount** |
|---|---|---|
| KfW-Effizienzhaus 55 | 40% of max. EUR 120.000 loan | up to EUR 48.000 |
| KfW-Effizienzhaus 70 | 35% of max. EUR 120.000 loan | up to EUR 42.000 |
| KfW-Effizienzhaus 85 | 30% of max. EUR 120.000 loan | up to EUR 36.000 |
| KfW-Effizienzhaus 100 | 27,5% of max. EUR 120.000 loan | up to EUR 33.000 |
| KfW-Effizienzhaus 115 | 25% of max. EUR 120.000 loan | up to EUR 30.000 |
| KfW-Effizienzhaus Denkmal | 25% of max. EUR 120.000 loan | up to EUR 30.000 |
| Individual improvements | 20% of max. EUR 50.000 loan | up to EUR 10.000 |

source: KfW Bank, n.d. b

contrast, the GEG states that the energetic requirements for new buildings and renovations will not be increased further (BMWi, 2019a). At the same time, the GEG provides substantial financial support for energy efficiency improvements on existing dwelling houses, which aims to reduce total heating energy consumption from households (measure #17). Moreover, the support program also includes energetic installations at households, such as photovoltaic (solar PV) or solar thermal systems, that produce heat or electricity for the respective households and further reduce the energy demand from common suppliers. Especially with regard to solar PV, which typically includes electricity feed-in to the public grid, the households are targeted to become prosumers. However, this transition is rather based on household participation than on regulation. The chosen policy approaches suggest that the government perceives the main hurdle and driver in this case to be the households' financial capabilities and spending preferences. Financial support schemes expand the available budget with regard to specific spending behavior. The subsidy structure by the governmental KfW Bank is illustrated in table 2.1.2.

The subsidies are awarded by the KfW Bank depending on the achieved efficiency value from improvement in comparison to the so-called KfW reference building. However, the KfW Bank only defines the KfW reference building to comply with the "Energieeinsparverordnung" (2007), which has been updated continuously in 2009, 2013, 2014, 2016, and 2020 and there is no fixed reference value of energy consumption per square meter attached to it (KfW Bank, n.d. a). Although different sources estimate the energy demand performance between 70 kWh/m2 and 100 kWh/m2 (Energie Wissen, n.d.; Energiesparen-im-Haushalt.de, n.d.; Niedrig-Energie-Institut, n.d.). The KfW Bank generally supports all sorts of investments. However, as portrayed in table 2.1.2 actual financial benefits only overs renovation measures that increase the insulation value of the floor, glazing, roof, and walls. Heating system installations as well as other energy production installations, such as solar panels, are only supported by means of loans. For insulation measures the amount of financial support is tied to the achieved efficiency efficiency level after improvement and capped at a maximum of 40% of the investment costs or EUR 48.000 for extensive building renovations and a maximum of 20% of the investment costs or EUR 10.000 for individual improvement measures (KfW, n.d. b). Due to the aggregated point of view instead of looking at the individual investment decisions in the modelling process, it should be assumed that households spending on upgrade and add-on projects amounts to a medium amount of the possible price range to be eligible for financial support. The governmental aid then extends the total spending on the improvement. However, as the conditions for the financial support are quite complex, in order to implement this support program accurately more insights on the typical energy efficiency improvement level from renovation processes are necessary. Appendix F shows that the required data could not be obtained, which makes this implementation difficult.

Nonetheless, installing improvements over time must then reflect a change in the yearly energy consumption characteristic of households, which should benefit the governmental energy transition targets. Additionally, as of 2021 the GHG emissions price discussed at the beginning of section 2.1 will also apply to the housing sector.

In summary, the energy transition in the housing sector is to a large extent being approached by giving financial incentives to households to lower their net energy consumption through energy efficiency improvements of buildings or renewable energy production installations as add-ons to buildings.

### 2.1.3 Energy transition: Personal transportation

As mentioned before, the transportation sector has achieved almost no GHG emission reductions since 1990 and has a great challenge ahead. According to the National Trend Tables for the German Atmospheric Emission Reporting provided by the Umweltbundesamt (UBA) (Gniffke, 2019), total transportation emissions were up by 3 million tons of CO2 equivalents in 2017 compared to 1990 levels and total emissions from road transportation were even up 7 million tons of CO2 equivalents. The sector for personal transportation covers a broad spectrum of transportation modes, including traveling by car, railway, airplane, public transport, which includes busses, trams, and metro systems, and cycling. For the purpose of this research walking is regarded as a means of connecting transportation modes and a local or recreational activity and will not be considered. Also personal waterway transportation in Germany is mostly a recreational or touristic activity and will thus be excluded as well. All other modes can be attributed with a purpose and utility value for the passengers and are thus meaningful to this research. Energy consumption in personal transportation is measured in energy used per passenger kilometer (Pkm), similarly the GHG emissions are measured in amount per Pkm. Thus increasing the occupation rate for any mode of transport is very effective for increasing the efficiency rating.

#### Railways, Public Transportation, and Cycling

The CPP2030 recognizes that immense transition efforts in the transportation sector are easier achieved with a distributed approach. Therefore the CPP2030 aims at simultaneously reducing the use of fossil fuels while incentivizing a shift to substitute fossil fuel intensive car travel with already more efficient public, collective transportation options. Consequently, the strategy involves multiple measures to increase the utility of railways and public transport systems. Improving the infrastructure and its maintenance as well as the service of railways and public transport providers can increase their connectivity and utility (measures #29, #30). Where the German railway infrastructure is only about 61% electrified with a target of 70% according to Deutscher Bundestag (2019a), the personal railway transportation is assumed to be almost fully electrified according to FIS data[1]. Public transportation has an electrification ratio of roughly 33% according to Destatis (46100-0021), which results mainly from the large diesel fueled bus fleet next to electrified tram and metro systems. However, many public transport operators have started to transition their bus fleet to electric busses (Lieb, 2019). At the present occupation rate of 19% diesel busses produce about 37% more GHG emissions than local trains (Umweltbundesamt, 2020). Nonetheless, with the current GHG emission characteristic of the electricity production also rail-based public transportation still produces almost 60g of GHG emissions per Pkm at a similar occupation rate (Umweltbundesamt, 2020). The public collective transportation modes share the common flaw of being limited to fixed routes and stops, which presents a significant drawback in accessibility, traveling time, and convenience for passengers as opposed to using the car. For most passengers there is a geographic gap between the starting point

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[1] www.forschungsinformationssystem.de

and the location of boarding a collective transport vehicle and between the location of disembarking and the final destination point. This gap can significantly be reduced by complementary infrastructure and transportation modes such as cycling. In consequence there is a complementary effect of improving the cycling infrastructure on the use of public transport (measure #31). Furthermore assuming that public transport also includes regional train lines due to similar function and emission characteristics (UBA, 2020), most people will use public transport to access railway stations. Thus there is also a complementary effect of improving the public transport infrastructure on railway utility. With regard to cycling, especially expanding and improving the network of cycle paths and bicycle stands and storage facilities at public transport stops and stations could greatly improve the utility and attractiveness of cycling with spillover effects on public transport and railway utility. Also cycling is experiencing rapid electrification in Germany. According to Fahrradportal (2019) and Statista (2020), the market share of E-Bikes was 23,5% in 2018 and even 29% in 2019, when a total of 4,18 Mio bicycles were sold in 2018. E-Bikes, of which most are sold as pedelecs, consume on average 7 Wh/km electricity (Rauch, 2011).

### Airtravel

Further, personal transportation within the scope of this research also includes national air travel, which amounts to roughly 14% of the total air travel in Germany according to the report by Radke (2019). All commercial passenger air travel is thus far purely fossil fuel based. However, several conglomerates have launched research projects on electrifying commercial aviation, with several projects undergoing late stage testing[2] also including the two leading manufacturers for commercial air planes Airbus[3] and Boeing[4] (Alcock, 2020; Electric Aircraft, n.d.). Therefore this research assumes a slow commercialization of electric aviation solutions by 2040 followed by a sector wide transition until 2100. In the meantime efficiency improvements through more sustainable production methods, such as bio-fuels or electricity-based fuels can be expected (measures #32, #33).

### Personal road transportation

The greatest contributor to GHG emissions from transportation is personal road transport by car (Wuttke, Junker, & Winkler, 2017). Road transportation is recorded and regulated by the Kraftfahrt-Bundesamt (KBA) in Germany. However, with the infrastructure and technological lock-in in mind, car transport is also the most difficult to transform to climate friendly technology. More than 47 Mio cars are registered in Germany, of which on average 90% are privately owned (Kraftfahrt-Bundesamt, 2020). Similar to household insulation, transitioning the car fleet is greatly determined by the consumption decision of car owners, the households. Therefore the German government maintains

Table 2.13: Government subsidies on electric vehicles

| type of car eligible for government subsidies | limit (list price) | maximum funding | end of program |
|---|---|---|---|
| plug-in hybrid vehicles (PHEV) | up to EUR 40.000 | EUR 7.500 | 31.12.21 |
| plug-in hybrid vehicles (PHEV) | EUR 40.000 - EUR 65.000 | EUR 5.625 | 31.12.21 |
| battery electric vehicles (BEV) | EUR 40.000 | EUR 9.000 | 31.12.21 |
| battery electric vehicles (BEV) | EUR 40.000 - EUR 65.000 | EUR 6.750 | 31.12.21 |

source: KfW Bank and "https://www.meinauto.de/lp-abwrackpraemie"

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[2] https://en.wikipedia.org/wiki/List_of_electric_aircraft

[3] https://www.airbus.com/innovation/zero-emission/electric-flight.html

[4] https://www.popularmechanics.com/flight/news/a28540/boeing-backed-electric-plane-fly-2020s/

a financial support program for electric vehicles (EV), which considers battery electric vehicles (BEV) and plugin hybrid vehicles (PHEV) as depicted in table 2.1.3 (measure #41).

The financial support is conditioned to the sales price and capped at a maximum price of EUR 40.000, aimin rather at the lower to medium income households. At the same time, the implementation of GHG emission pricing, mentioned at the beginning of section 2.1, is a lever to increase the operating costs of combustion engine vehicles (CEV) by increasing the levies on fossil fuels.

Several points have been raised against the planned effort regarding personal transportation. The limited term of the support program is strongly criticized for being too short and too little of an incentive to spur an industry-spanning transition to environmentally friendly transportation. At the same time a total of 1 Mio electric vehicles (EV) are supposed to be registered by 2022 (BMWi, n.d.) but by 2020 barely 150 thousand EVs were achieved of which about 64 thousand (43% of the total) were newly registered only in 2019 according to KBA data. The government aims to have 7 to 10 Mio registered EVs by 2030 according to the CPP2030. However, Kungel (2019, November) and Heiman (2019, May) strongly criticize the low effort of the government to achieve its goals. Introducing the case of Norway where roughly 50% of new registrations are EVs, Kungel (2019, November) proclaims that the incentives on EVs are far too low to make significant change. He further argues that the households occupying about 16 Mio single family houses in Germany should easily be able to maintain EVs, charging them at home most of the time except for vacations a few times a year. In that case the public charging infrastructure would already be sophisticated enough to recharge for long distance travel, he continues (Kugler, 2019, November). Assuming the average annual driving performance is 15.000 km and two or three long distance trips per year cover between 3.000 and 5.000 km, leaves an average driving distance of 27 to 33 km per day, which even small batteries can cover and could easily be recharged in a few hours during the night with the standard house connection to the electricity grid (Fraunhofer ISE, 2020; Kungel, 2019, Nov). Also the planned GHG emission pricing may turn out to be a mere flash in the pan. At a proposed starting minimum price of EUR 25 per tCO2equ the GHG emissions tax would increase petrol fuel prices by about EUR 0,07 per liter, an equivalent of roughly EUR 0,50 per 100km. Záboji (2019, Sep 21) strongly criticizes the effectiveness of such low prices. Even with the planned minimum price increase to EUR 55 per tCO2equ by 2025, resulting in additional EUR 0,145 per liter and EUR 1,05 per 100km to the base operation costs of petrol cars, is not expected to have significant effects, according to Záboki (2019, Sep 21) and Kungel (2019, Nov). Considering that the resulting expected damages from GHG emissions in health and environment are estimated at a price of EUR 180, the in the CPP2030 intended pricing levels may remain inconsequential to consumer behavior (Umweltbundesamt (UBA), 2018, Nov 20).

Further expansion of the charging infrastructure and of refueling stations for alternative fuels is still an important lever to increase the utility and attractiveness of EVs and other technologies (measure #39). At the same time, traffic in itself produces significant inefficiencies that could be alleviated with increased automation of traffic by fully leveraging newest communication and control technology (measure #40).

Admitting that not all cars are suitable to run on present battery electric technology and to increase the efficiency of remaining CEV, the government simultaneously seeks to increase the sustainability of petrol and diesel fuel by supporting the development of advanced bio-fuels. Additionally, the government is equally determined to further expanding the public charging infrastructure with special consideration also of fast charging stations for long distance travellers. The planned infrastructure measures also extend to other alternative fuels and technologies, such as bio fuel, bio gas and hydrogen.

In summary, the approach concerning a transition in the personal transportation sector follows an integrated approach with the intention of spreading the effort and thus reducing strain on the system and the citizens. Personal road transportation is further influenced by the implementation of GHG emission prices. However, criticism arose regarding the effectiveness of this broad approach.

### 2.1.4 Interdependencies between the focal sectors

All three discussed sectors share similar policy approaches and can be expected to influence each other in the long run. The relationship of the energy sector to transportation and housing is obvious, nothing works without energy. Yet also the transportation and housing sectors share a significant connection. In both sectors the government plays on the households' ability to finance the transition. In combination this implies a potential double burden for households. However, assuming that individual households focus their efforts, they will choose to invest in one improvement at a time among the specific housing improvements and car upgrades. And since such investments are voluntary and households will only commit if they perceive it worthwhile, the given measures are not a burden at all. In consequence, the policy strategy's great obstacle is the problem of consumer preferences that drives the transition in both the housing and the personal transportation sector. The government applies incentive measures that from a household's point of view present alternatives and could thus cannibalize each others effects. This problem is further discussed in section 2.2 on policy dimensions.

Additionally, household heating and transportation use similar fuel sources, where both sectors have been using fossil fuel derivatives in parallel for a while without issues. Present policy measures, however, suggest a simultaneous move into bio-fuels and electricity (or hydrogen in the future), which could have stronger implications on the transition speed.

Furthermore, moving out of fossil fuel transportation into electric propulsion significantly implies a drop of fossil fuel consumption and could therefore result in a price drop for fossil fuels. Since multiple countries have vowed similar transition efforts according to the Paris Agreement (United Nations, 2015) similar price drops could well be expected in the medium to long term. However, fossil fuels are traded internationally and this research only considers one small to medium sized country, which has virtually no price-setting power. Therefore the international mechanism of energy prices would attenuate the proposed price effect.

Considering the set of policy measures and the implied interdependencies highlights four dimensions in which the government can act to achieve the energy transition. Thus far the government appeals to (a) financial capabilities and (b) the attractiveness and utility of behavior change as components of consumption preferences. Additionally, the third dimension concerns (c) the freedom of choice as opposed to limiting specific services or behavior. In contrast, the fourth dimension involves (d) publicly providing free services in order to spur collective behavior change.

## 2.2 Policy dimensions and implications on modelling

The four dimensions of policy measures can be distinguished in direct and indirect measures. Direct measures immediately address the issue at hand, like imposing limits and quotas on vehicle sales or publicly providing a specific service. Instead, indirect measures address the value system of consumers, which are the foundation for consumption preferences and behavior. In this case, a policy aims to encourage or discourage a specific behavior, such as achieving lower vehicle sales by raising the price on vehicles. In summary, policy making can apply various different means to achieve its goals. However, especially direct restrictive measures that limit the freedom of choice are not only criticized as a strong intervention in the open market economy but also clash with the autonomy of citizens and their freedom of choice. The EU-wide ban of conventional light-bulbs in 2012 was not well received by the public and businesses (EU bans old-fashioned light bulbs, 2009). Even more controversial are recent bans on diesel cars in several city centers in Germany (ADAC, 2020, February; Wo "Diesel-Fahrverbote gelten oder drohen", 2019). Both measures were implemented in the name of climate change and both but especially diesel car bans were a measure of last resort of cities to mitigate fines for exceeding pollution levels. Thus direct approaches have the advantage of being time sensitive whereas indirect approaches take as long as citizens need to adapt their behavior.

As stated above, indirect policy strategies leverage the incentive mechanisms that respect the open market's spirit of freedom of choice while addressing the consumption preferences of citizens and are thus much more socially compatible and acceptable as direct measures. Such instruments commonly include policies setting financial incentives through subsidies on favored and taxation on unfavored consumption but can also policies that grant other public benefits as can be achieved by executing infrastructure projects that are aimed to improve the relative utility of targeted behavior and technologies and thus can evoke change. Such can be a dedicated cycling path that is built to connect two frequently visited locations, which improves the utility of bicycles so that more people may refrain from taking the car and burning fossil fuels. How many people will follow this incentive depends on many factors, including the surrounding plans for the day that visitors have made in combination with a trip to one of the locations. This example therefore highlights the policy's dependence on the choices of individuals and how well this policy manages to address the "pain points" of people in this environment. If there is no interest of people visiting both locations in combination, for example because they house the same shops and therefore are considered to be substitutes instead of complements, the new bike path will have little effect on the utility in this regard and the initial infrastructure investment deflagrates into thin air. These examples also illustrate the complexity and uncertainty that is inherent to such indirect policy levers. Therefore it is worth taking a closer look at the societal areas that have the greatest potential to influence the energy transition.

### 2.2.1 Financial and non-monetary resources

First and foremost, the financial capabilities play a major role in our society and thus also determine the yearly budget of public institutions and households to invest in new infrastructure, vehicles, and upgrades. Therefore, household budgets and supplementary income and spending mechanisms with respect to the designated energy transition focal areas form additional vital sub-systems. The financial capability is further accompanied by spending preferences and everybody's will to accept possible changes. Such are flanked by governmental support schemes on environmentally friendly upgrades and vehicles and the taxation of GHG emissions (carbon tax), both potential policy levers. Additionally, the price development of internationally traded goods, such as fossil fuels and electricity but also upgrade materials and cars, present external factors that influence effectively available financial budget for the energy transition. Second, a comprehensive transition out of fossil fuel power into renewable energy inevitably requires a significant change in demand of non-monetary resources. The need for natural resources like coal and oil turns into a demand for metals and concrete. The types of finished products change from combustion engines to batteries for electric vehicles, and heating and cooling system parts of power plants to wind turbine elements. Additionally, the demand for insulation materials or solar installations for every household gains in importance. Workers are needed more to accomplish various upgrades and installations on buildings or build and maintain wind and solar power plants, rather than work coal mines and power plants. Similar to the available budget, these resources also present a potentially limiting factor for the energy transition. Obviously, the limiting potential of any of the mentioned resources further increases with the limited time frame of the energy transition. It is unclear whether the financial budget, production capacities and available labor force can achieve the yearly transition efforts necessary to finish by 2050.

### 2.2.2 Social factor of choice

This generally captures the actors and factors that will determine the outcome and speed of the energy transition. Yet again, the social factor needs a bit more emphasis. In summary, the depicted internal and external factors present again a problem of balance between the demand for the (production) factors of money, materials and labor and their supply by the people, industries and the government. However, with the urgent need to reduce GHG emissions, the consumers turn out to be the deciding factor in what is a typical "chicken and egg" problem revolving around the economy (demand-driven vs. supply-driven market). Thus in case of the energy transition it is the consumers that must act to request the products, materials, and workers in order to perform the energy transition. Most countries, follow an open-market economy in which economic values play a significant role in structuring society, in which the market is a nexus in society that determines what is produced, consumed and invested in. In abstract terms, the market is a clash of personal values and the relative cost of utility from which result consumption decisions, which, in the greater picture, do not naturally align with ethical norms and what is right or needs to be done. People act neither rational with regard to market prices nor with regard to their personal conviction and values and thus the collective behavior of a society is considered unpredictable. Take the measures intended to spur EV sales for example. The governmental subsidies significantly reduced EV sales prices and the automobile club ADAC e.V. prognosticates significant operating cost benefits for EVs, not to mention the short and long term environmental benefits (ADAC, 2019). These advantages are opposed by inconveniences regarding the range and recharging behavior of EVs in combination with the slow progress in infrastructure expansion. In essence, certain, quantifiable financial benefits stand against uncertain, less quantifiable behavioral objections.

Hereto, Storm (2017), a renowned scholar of economics, stresses that the required change in an open-market economy is not trivial and countries are working hard to find adequate strategies for transitioning to carbon-neutral societies as the track record shows. He underlines that consumers cannot be expected to do what is necessary just through economic incentives and suggests that stricter governmental interventions, such as quotas and limits, may be necessary to bring about fast and radical change in order to mitigate climate change. Kungel (2019, November) also argues that the present financial incentives on EVs are not enough to initiate the transition in the transport sector. However, in contrast to strict regulation of CEV, he introduces the example of Norway, where today about 50% of the country's car fleet are EVs without the Norwegian government ever imposing restrictions on CEV. Kungel (2019, Nov) rather points out that intensity of indirect measures is important to achieve the energy transition. This is highly relevant for the undertaking of this research as it suggests to consider a wider range of policy levers including those restricting the choices for consumers.

### 2.2.3 Radical policy approaches

The Norwegian case demonstrates how radical yet socially compatible approaches are possible to achieve the energy transition. The extraordinary number of new EV registrations in Norway results mainly from import tax exemptions on EVs, where typically roughly half the sales price of cars are import taxes (Lambert, 2016; Norsk elbil forening, n.d.). This significantly counteracts the otherwise significantly higher base sales price of EVs. As a result buying an electric vehicle in many cases turns out to be cheaper than buying a conventional car, even more so when the electricity and fuel costs are considered. At the same time, Norway is investing significantly in charging infrastructure and is granting other benefits to EVs, further raising the overall utility of EVs according to the Norsk elbil forening[5].

However, other examples also show effective and accepted restrictive measures on car use. Depending on a day's air quality, Mexico City for example is restricting the use of cars with even and uneven license plate numbers in an alternating fashion in order to reduce air pollutio. Implementing restrictive measures is more common in the business sector though. Policy-making more readily considers stricter approaches that resort to restrictions of specific technologies, processes and materials for businesses as demonstrated by phase-out policies for nuclear and coal fired power plants, for example (Presse- und Informationsamt der Bundesregierung, 2011 & 2020).

Additionally, several politicians and public leaders proposed to make public transport in cities freely available to every citizen as an option to reduce traffic and inspire behavior change. Thus far the idea met strong opposition and remained limited to individual short term trials (Conrad, 2020; Parth, 2019; Theiding, 2019).

### 2.2.4 Implications for an energy transition model

Following this deep-dive, the subject's complexity becomes palpable. Additionally, the sectors or subsystems in question could become even more intertwined as a result of the energy transition, which may suggest the merging of systems or require a redefinition of their boundaries. With a transition from the internal combustion engine (ICE) to battery electric vehicles (BEV), for example, vehicles can be expected to no longer be refueled at external gas stations but to a large extent at home via the household's connection to the electricity grid. Would that be an indicator to conceptualize the use of cars and household consumption in one combined sub-system in the future? Additionally, households may be encouraged to install solar energy collectors through which they would take part in a country's total energy production in terms of heat energy and electricity. How would that affect the conceptualization for useful policy-making in the energy transition? Thus policies may or are meant to cause change and therefore should undergo regular revision. Of course, every policy must respect its country's individual properties and weigh the policy options accordingly.<<

In conclusion, there are various systems directly and indirectly linked to the use of energy that are crucial in considering during policy formulation. Structuring the problem in systems and subsystems with the policy goal in mind enables to account for the individuality of the problem per area, thereby reducing the complexity and increasing effectiveness and efficiency in policy-making. The approach requires to identify the key actors and stakeholders of the problem at hand and more importantly to understand their relationships and individual levers of influence within the system. The understanding and detailed knowledge about how the world works therefore increases the quality of policies. However, systems thinking alone is not the salvation because the world is just too complex.

## 2.3 System boundary definition

The system boundary can be captured by following several modelling dimensions. The dimensional choices may on the one hand be limited by restricted data availability but are on the other hand a determinant for the modelling resolution, where "model resolution is the level of structural and behavioral detail that events, mechanisms, processes, etc are described in" (Nicolic et al., 2019a:9). The relevant dimensions in this context are:

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[5] https://elbil.no/english/norwegian-ev-policy/

- geographical level
- time horizon
- energy units
- societal detail
- technological detail

Aggregating the outcomes of a high-resolution model is by far easier than disaggregating outcomes of low-resolution models. Additionally, lower level insights promise to be more useful for operational decision making, such as on municipal level (Verburg et al., 2016). The down-side of higher resolutions, however, obviously lies in the computational cost, as mentioned before. The system boundaries are derived from the case description in combination with the present policy approaches in the German energy transition. The full overview of the limits is outlined in the Appendix B.

**jsaid, Criqui, &**
**Trutnevyte and**
**et al. 2015)–>**

## 2.4 Political decision making under deep uncertainty

Quantitative modelling and simulation techniques are commonly used for informing political decision making on interdisciplinary, complex problems (IPCC, 2014; United Nations, 2018; United Nations, 2015). The Dynamic Integrated Model of Climate and the Economy (DICE) for example was developed by Dr. William Nordhaus (2008) in order to estimate the social cost of carbon, which represents "the cumulative economic impact of the global warming caused by (or attributed to) each tonne of the pollutant sent into the atmosphere" (The cost of climate inaction, 2018). As mentioned before, complex problems come with high levels of uncertainty. The levels of uncertainty are presented in this section followed by the proposition to use robust decision making to mitigate uncertainty in decision making problems. Finally, the exploratory modelling and analysis approach is introduced to find robust policies in the context of the simulation modelling.

### 2.4.1 Deep uncertainty in political decision making

The energy transition is an interdisciplinary research challenge (Li, Trutnevyte and Strachan, 2015). Supposing that there is a clear political goal, such as to reduce GHG emissions to zero by year 2050, a political strategy entails a profound comprehension of the problem. Yet, it is so complex that capturing every aspect of it is nearly impossible. Additionally, the energy transition involves not only switching from coal-fired power plants to solar and wind power plants but also assimilating new societal behavior patterns. Considering the implications and directly as well as indirectly affected people of such changes illustrates the vastness of the challenge. Definitively defining the problem is highly complex and finding the one optimal solution is basically impossible. Rittel and Webber (1973) called these "wicked" social problems as opposed to "tame" scientific problems, signifying the super-complexity of societal issues.

Lempert, Popper and Bankes (2003) coined the phrase "decision making under deep uncertainty" , describing planning problems like the energy transition that are further made under unavoidable and irreducible uncertainty. As opposed to traditional uncertainty, deep uncertainty implies that involved parties to a decision can neither agree on nor exactly know the system and its boundaries, the desired outcomes and their comparable importance, or the prior probability distribution for the uncertain inputs to the system (Lempert et al., 2003). Under deep uncertainty even the problem definition is subject to change. Haasnoot, Kwakkel, Walker, and ter Maat (2013) illustrate that there are many plausible alternative models with "alternative sets of weights to assign to the different outcomes of interest, different sets of inputs for the uncertain model parameters, and different (sequences of) candidate solutions" to such problems (Kwakkel, Walker, & Haasnoot, 2016:1). Subsequently, decision making under deep uncertainty is classified a specific form of wicked problems (Rittel and Webber 1973). Lempert, Groves, Popper, & Bankes (2006) briefly summarize deep uncertainty to be circumstances in which parties involved in a decision making process do not know or cannot agree upon:

- how interaction takes place between system variables and their appropriate model representation,
- which probability distribution best represents the uncertainty of key parameters, or
- how to value the preferences of alternative outcomes

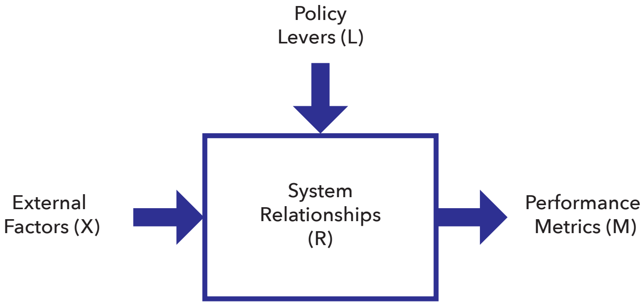

Figure 2.5.3: The XLRM framework
Adopted from Kwakkel (2017)

Simulation modelling scholars propose to apply a combination of advanced stochastic methods for systemic uncertainty in political decision making. However, deep uncertainty in complex adaptive systems "is the result of pragmatic limitations in our ability to use the representational formalisms of statistical decision theory to express all that we know about complex adaptive systems and their associated policy problems", according to the understanding of Bankes (2002). In consequence, supporting the line of argumentation of Rittel and Webber (1973), Lempert, Groves, Popper, & Bankes (2006) express that in political decision making optimal solutions do not exist and that under deep uncertainty rather "robustness may be preferable (…) as a criterion for evaluating decisions" (p. 514).

### 2.4.2 Robust decision making

As pointed out in chapter one, policy making is severely impaired by uncertainty and complexity, so that there is no perfect solution to a problem that makes everyone happy. The classical understanding of optimization refers to single strategy with a specific distribution of probability over the uncertainties produces a single best outcome, according to Lempert et al. (2006). However, traditional decision analysis approaches are unsuitable for political decision making problems as the number of stakeholders per definition is not able to agree on a desired outcome (Walker et al., 2013). In consequence, the scientific community and practitioners agree that robustness of policies is the favorable benchmark in political decision making.

The definition of robustness varies from field to field but the essential understanding is the same. Robustness characterizes a set of policies that produces the most favorable outcomes for all stakeholders while causing the least pain. In other words, when policies perform well in a multitude of different future states. (Kasprzyk, 2013; Kwakkel, Haasnoot, & Walker, 2016). Defining reference values for good and bad outcomes, the robustness can be made measurable in a systems approach.

### 2.4.3 Exploratory Modelling and Analysis

Specifically useful in societal decision making problems, simulation models evaluate how systems evolve over time and can thereby raise awareness of possible future challenges and determine potential impact of individual uncertainties on future outcomes (Pfenninger, 2014; Verburg 2016). Simulation models, just as the one conceived here, are made to generate vast numbers of possible pathways that the respective system could take. Each pathway or scenario presents a possible future state of the system it represents. Simulation models are predestined to integrate various sources of uncertainty, which further add to the range of scenarios (Better et al., 2008). Finally, evaluating different policy options over this large ensemble of scenarios allows to determine robust policies by applying Exploratory Modelling and Analysis (EMA) techniques as proposed by Bankes et al. (2002). By means of computational experiments the EMA approach systematically explores the behavioral response to different policy settings of complex systems under a set of predefined uncertainties. Lempert et al. (2003) thought of the XLRM framework as the first step in the robust decision making (RDM) methodology, which represents the EMA approach.

Considering that models are created to support the decision making process of a client or so-call principal, the XLRM framework distinguishes external inputs to the model (X), policy levers (L), the system relationships (R) and the model outcomes (M), which are defined as follows:

- X: The external factors represent influences that are not under the control of the principal and potentially carry great uncertainty and risk; things that are, can or will happen
- L: The (policy) levers describe actions that the principal controls, such as alternative decisions
- R: The system relationships explicitly describe the relations between elements within the system boundary; the causal relations between external factors (X), levers (L) and outcomes (M)
- M: The performance metrics describe the outcomes of interest, which are the expressions of impact of actions; what is measured; how it is measured

With the XLRM framework in mind, follows an iterative process in which can involve expert opinion or sensitivity analysis in order to identify candid policy strategies. The framework presents a structural approach the policy problem. With a keen eye on the performance metrics, the policy levers and external factors can be combined systematically to find policy combinations that are comparatively more robust to others with respect to the external factors. This approach in essence relies on brute force trial and error in the first steps. After obtaining the first insights the next steps become more methodical, leveraging the new insights. An optimal approach was presented by several scholars as outlined in the follwing.

Specifically useful in societal decision making problems, simulation models evaluate how systems evolve over time and can thereby raise awareness of possible future challenges and determine potential impact of individual uncertainties on future outcomes (Pfenninger, 2014; Verburg 2016). Incorporating multiple approaches, scholars suggests to combine exploratory modelling and analysis (EMA, Bankes, 1993; Kwakkel and Pruyt, 2013) and many-objective robust decision making methodologies (MORDM, Kasprzyk, Nataraj, Reed, & Lempert, 2013; Watson, & Kasprzyk, 2017) for evaluating political decision making problems (Kwakkel, 2017; Kwakkel, Walker, & Haasnoot, 2016; Lingeswaran, 2019; Moallemi, Elsawah, & Ryan, 2018; Nicolic et al., 2019; . Watson & Kasprzyk, 2017). This combined approach further integrates the objectives and strengths of previous research on robust decision making (RDM, Lempert, Groves, Popper, & Bankes, 2006; Gabrel, Murat, & Thiele, 2013), multi-objective evolutionary algorithms (MOEA, Coello Coello, Lamont, van Veldhuizen, 2007), multi-objective robust optimization (MORO, Gabrel, Murat, & Thiele, 2013; Hamarat, Kwakkel, Pruyt, & Loonen, 2014), and dynamic adaptive policy pathways (DAPP, Haasnoot, Kwakkel, Walker, and ter Maat, 2013).

These different methodologies are dealing with the key issues found in decision making under deep uncertainty and wicked problems. In summary, applying EMA in combination with MORDM frameworks focuses on (1) developing robust strategies as the maxim of perfection (RDM, MORO, MORDM), as well as (2) adaptive strategies that are able to follow changes in the system as well as in the problem definition, which are dynamic in wicked problems under deep uncertainty, (MOEA, DAPP, MORDM, EMA), (3) optimizing over multiple objectives simultaneously that reflect the diversity of societal and wicked problems respectively (MOEA, MORO, MORDM), (4) exploring potential scenarios as a tool to look into possible futures of a system and enable better ex ante evaluations and decision making thereby moderating deep uncertainty characteristics (DAPP, MORDM, EMA). A serious concern of combining a number of different stochastic methods in one framework is the computational cost that was addressed before. Hamarat et al. (2014) notes that “multi-objective optimization and robust optimization in isolation are already computationally intensive” (p.36), further expanding the approach with exploratory modelling and evolutionary algorithms could exponentially increase the computational cost. The technological progress, advances in hardware capacity as well as modelling methods, is enabling higher levels of complexity in models but the trade-off modelling time and computational cost versus model-accuracy remains important (Flato et al., 2013; Nicolic et al., 2019; Pietzcker et al., 2017; Yilmaz, Taylor, Fujimoto, & Darema, 2014). However,…

… quantitative methods only work well with extremely large numbers of experiments, optimally multiple thousands, because the method benefits from simulating as many possible outcomes as possible. This in turn, though very informative is also very computational expensive. As a baseline to indulge in applying the EMA approach in combination with MORDM, the standard model should be able to complete one simulation run within a matter of seconds to be able to complete on a standard laptop. As an alternative, a manual approach is chosen, which includes basic sensitivity analysis and visual evaluation.

# 3 Methodology

The previous chapter illustrated the case of the German energy transition challenge and especially pin-pointed the challenges in transitioning housing and personal transportation to a sustainable pathway. Furthermore, section 2.4 presented modelling and simulation techniques as recommendable approaches to complex decision making problems such as this. Now it is time to initiate the modelling process by first deciding on a suitable modelling approach (section 3.1), conceptualizing the model components to describe the research problem (section 3.2), and defining the elements of the XLRM framework to enable exploratory modelling and analysis (section 3.3). Additionally, the data collection process and structure of the used data are elaborated (section 3.4), followed by summarizing the core assumptions of the model (section 3.5).

## 3.1 Choosing the modelling formalism

Different modelling techniques have been developed to tackle policy problems. The so-called modelling formalism refers to the modelling technique that is used. It is chosen dependent on the point of view and the kind of system and mechanisms the model shall represent. Initially, the point from which the modeller views a system determines the choice in modelling formalism, e.g. whether taking a high-level, top-down perspective or rather a grassroots, bottom-up perspective favors a different approach, as illustrated by Crespo del Granado, van Nieuwkoop, Kardakos, and Schaffner (2018). This section is dedicated to determining a suitable modelling formalism to answer the research questions.

As outlined in the problem definition (section 1.1), this research aims to evaluate how different political alternatives and measures may play out in the three focal sectors and how suitable they are to achieve the GHG emissions reduction targets by 2050. Among the different modelling approaches, the features of the energy transition as a societal problem can best be represented by system dynamics (SD) and agent-based modelling (ABM) (Filatova, Polhill, & van Ewijk, 2016).

### 3.1.1 System Dynamics (SD)

SD models take a top-down point of view, looking at the greater picture of a system, concerned with analyzing the dynamics between the system elements, characterized by asymmetric and transitive relationship that form reinforcing or balancing feedback loops, and that run over long periods of time applying differential or difference equations. Forrester (1990) developed the system dynamics approach in the 1950s as a quantitative tool to evaluated feedback loops in abstract systems in a short amount of time. Filatova, Polhill, and van Ewijk (2016) see the strength of SD modelling in the ability to easily describe and qualitatively analyze a system's behavior with causal loop diagrams. They further argue that while SD models are also strong in representing feedbacks, macro-level processes and complexity, they have difficulty to evolve. Similarly, Verburg et al. (2016) call for the development of "novel system representations that focus on the representation of feedbacks between socio-ecological systems across different scales and the representation of human processes" (p.338) in order to advance in solution-oriented research for Anthropocene challenges. SD models have been applied to disease spread and intervention (Pruyt, Auping, & Kwakkel, 2015), ecosystem and population dynamics (Auping, Pruyt, & Kwakkel, 2015; Filatova et al., 2016), energy systems and transition (Bhattacharyya & Timilsina, 2010; Crespo del Granado et al., 2018; Li, Trutnevyte, & Strachan, 2015), as well as resource flow problems (Kwakkel & Pruyt, 2013).

However, this abstract approach is limited in its ability to represent detailed, complex relationships. SD modelling is severely impaired to simulate individual decision making processes and individual behavior of actors. The SD formalism cannot represent individual actors, only aggregated action by implied individual actors, which makes it unsuitable for analyzing decision-problems on an individual level.

### 3.1.2 Agent-based modelling (ABM)

As opposed to SD modelling, ABM assumes a bottom-up view and investigates complex systems defined by heterogeneity, feedbacks and adaptation. Actors that make individual adaptive decisions are typical for societal systems. Verburg et al. (2016) summarize that despite IAMs dominating the model-based research on the Anthropocene dynamics "(…) they are not fully equipped to represent emergent patterns, regime shifts and cross-scale dynamics." (p.338). ABM presents a valid option to solve said deficits as it is specifically useful to study endogenous feedbacks and the emergence of regime shifts. The ABM formalism is predestined to model systems of individual, spatially distributed, heterogenous actors, such as citizens in a town or country, who can move and interact and thereby produce a vast range of emerging patterns of behavior that need not be conceived by the modeller (Eppstein, 1999; Gotts et al., 2019). In consequence, ABM can be utilized to evaluate adaptive behavior as a response to environmental changes can be realized through individual or social learning, for which also machine learning algorithms may be applied (Filatova et al., 2016). However, comprehensive ABM models over many scenarios require large-scale simulations wherefore Filatova et al. (2016) argue that they are typically focused to a small number of scenarios or to compare specific scenarios as opposed to covering a whole system state space. ABM has so far been applied to specific problems in energy transition and infrastructure problems (Kwakkel & Pruyt, 2013; Kwakkel & Yücel, 2014; Li, Trutnevyte, & Strachan, 2015), ecosystem, land use and population dynamics (Filatova et al., 2016).

Due to its high level of detail, simulating individual actors with dedicated choice algorithms can become very resource intensive very quickly. ABM benefits greatly from large numbers of actors but in consequence can handle only a limited number of choices and assumptions. Additionally, Fontaine and Rounsevell (2009) criticize that ABM assumes that choice algorithms and preferences remain constant over the simulation time, which may be in contrast to today's fast-paced society. Furthermore, accurately capturing the possible choice mechanisms to implement in actors remains a core challenge in ABM (Zhang et al., 2016; Fontaine and Rounsevell, 2009).

### 3.1.3 Choice of the modelling formalism

Consequently, system dynamics modelling is the preferred modelling formalism for this research. SD assumes the desired bird-view-perspective on the system as a whole. With SD modelling, the focal sectors' energy transition systems are described as aggregated stocks and flows, summarized on the chosen level of aggregation. These core qualities are key to gain insights about the energy transition dynamics and evaluate the different policy options for Germany as a whole or its political sub-entities, such as states and administration districts.

Zeigler (2000) notes that different modelling approaches can also be combined and used as hybrid models considering the modelling goal. Verburg et al. (2016) agree that "a pluralistic approach that tests different alternative model structures is required" (p.338) in order to combine the individual strengths and address the different challenges posed by the Anthropocene. However, such undertaking, even though very interesting, lies far outside the scope of and means available for this research.

## 3.2 Data

This section briefly covers the sources and accuracy of the data in use. The specific datasets used in this research are a result of the need of specific data points, fulfilling the desired aggregation level and data format, and the availability of data points that match this need as good as possible. In the course of data collection, a master dataset is created, which collects and prepares the different datasets in one file under a uniform structure in order to improve its application in the simulation. The file also notes the data sources. Furthermore, it is outlined how the inevitable gap of missing data was overcome, how the model was parametrized and how data is being used. Finally, the handling of uncertainty is outlined with respect to affected data points.

### 3.2.1 Input data selection

In order to enable an evaluation of energy transition policies in Germany, datasets on the societal structure are needed as well as specific data points that further define the energy consumption and GHG emission properties of the societal structure. Generally, the federal data services including Destatis[1] and Genisis-Online[2] databases are the starting point for all societal data searches. Below, the data structure and the sources are presented for each of the focal sectors.

Wherever possible original data is used, however, some data is not available in the chosen resolution. In such cases the closest available data points are used to bridge this gab and spread or infer the available distribution onto the desired resolution.

**Data selection: Energy sector**

Energy consumption related data is also found on the aforementioned databases, however, the Working Group on Energy Balances (short AGEB for Arbeitsgemeinschaft Energiebilanzen e.V.) is a society dedicated to preparing and publishing various energy-related statistics for Germany. Therefore, the initial data to represent the relevant parts of the energy sector, such as the composition of the electricity mix and the electricity demand of non-focal sectors, is found in the AGEB datasets. All energy data in this sector is aggregated to the national level.

Additionally, several data points are required to calibrate the model, which could be found in different reports and online tools. The Deutsche WindGuard (2018a, 2018b), for example, provided valuable insights into the dynamics in the on- and off-shore wind sector. The Bayrisches Landesamt für Umwelt (LfU) (2018) published a tool and summary on the energy value and emission characteristics of different fuels.

The three price-setting mechanisms for electricity, fossil fuels and GHG emissions are informed by historic values, taken from different online sources. As these prices change daily by a few cents, a rough estimate is enough for this study so that virtually source is sufficient. Specifically Fluessiggas1[3], Strom-Report[4], and Wikipedia[5] provide useful information. Additionally, the GHG emissions price policy decision from the BMWi (2020) is included. Valuable data points on solar pv energy is also provided by Fraunhofer ISE (2020).

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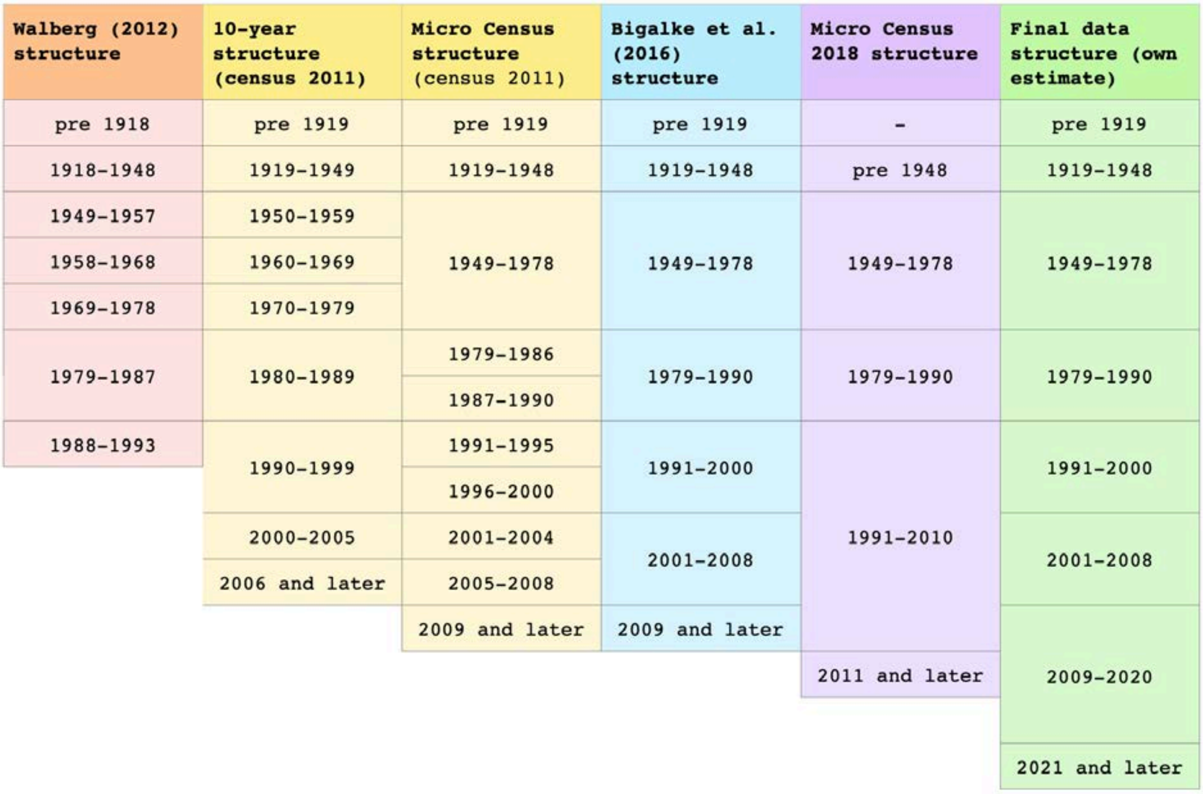
[1] www.destatis.de
[2] www-genisis.destatis.de
[3] www.fluessiggas1.de
[4] www.strom-report.de
[5] www.wikipedia.org

## Data selection: Housing sector

The housing sector is founded on disaggregated datasets provided by Destatis. The initial amounts of buildings, dwellings, and living space are integrated on the level of administration districts. However, most recent dataset available with such high resolution originates in the census of 2011 (further referred to as "census11"). Since the census11 did not cover all necessary data points, such as living space distribution, household income, and types of heating systems, the micro census of 2018 (further referred to as "mc18") is used to estimate the missing data. The mc18 is based on a 1% sample of the population and extrapolated to represent the whole society. In contrast, detailed data on a broader range is collected with the micro census. Due to the small sample size, the mc18 data is aggregated on national and state level. Thus upon extracting the desired data points, the mc18 data distribution is mapped over the higher resolution census11 data, which in the following will be treated as the master dataset.

In order to estimate the energy efficiency performance and upgradability of buildings and living space, specific data is needed. However, buildings and living space are different from case to case, whereas this modelling attempt operates on a rather aggregated level by applying average values. Thus multiple online-sources are searched through in order to get a feeling for the best estimates on building specifications. Such include Westermann & Richter (2018) for application-specific energy consumption in households, Heizung.de[6] for electricity consumption per household size, Niedrig-Energie-Institut[7] for the energy efficiency characteristics of new constructions, Energie-Fachberater[8] and other insulation and energy installation providers for data on insulation improvements and energy production, and Walberg (2012) and Bigalke et al. (2016) on energy efficiency performance per square-meter, building size, and construction year in addition to Destatis data. These data sources provide only very selected and specific data points. Thus some may turn out to be useless in the course of modelling as the structure of one set may not fit to the structure of other data.

Table 3.2.1-a: Different housing data structures



| Walberg (2012) structure | 10-year structure (census 2011) | Micro Census structure (census 2011) | Bigalke et al. (2016) structure | Micro Census 2018 structure | Final data structure (own estimate) |
|---|---|---|---|---|---|
| pre 1918 | pre 1919 | pre 1919 | pre 1919 | - | pre 1919 |
| 1918-1948 | 1919-1949 | 1919-1948 | 1919-1948 | pre 1948 | 1919-1948 |
| 1949-1957 | 1950-1959 | 1949-1978 | 1949-1978 | 1949-1978 | 1949-1978 |
| 1958-1968 | 1960-1969 | | | | |
| 1969-1978 | 1970-1979 | | | | |
| 1979-1987 | 1980-1989 | 1979-1986 | 1979-1990 | 1979-1990 | 1979-1990 |
| | | 1987-1990 | | | |
| 1988-1993 | 1990-1999 | 1991-1995 | 1991-2000 | 1991-2010 | 1991-2000 |
| | | 1996-2000 | | | |
| | 2000-2005 | 2001-2004 | 2001-2008 | | 2001-2008 |
| | 2006 and later | 2005-2008 | | | |
| | | 2009 and later | 2009 and later | | 2009-2020 |
| | | | | 2011 and later | |
| | | | | | 2021 and later |

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[6] https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/

[7] https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/

[8] www.energie-fachberater.de

One example incompatible data structures is the different ways of clustering the building construction year groups as illustrated in table 3.2.1-a. The census 2011 data (yellow) collection provides building data in two alternative forms of aggregation, by 10-year groups and by so-called micro census groups. Although bearing similar names, the micro census 2018 data (purple) does not fully correspond to this format. The structure of Bigalke et al. (2016) (blue) resembles an aggregated version of the micro census data presented in the census 2011 dataset. However, Walberg (2012) (red) provide data on building standards and efficiencies that is for once limited to the year 1993 and presents many differences to the other structuring formats. Since its content is similar to that of Bigalke et al. (2016) yet has less data quality, the data from Walberg (2012) is disregarded. Despite the differences, all three datasets contain valuable information and need to be combined. The final data structure (green) is thus created with the intention to most efficiently and with as little intervention as possible join the three datasets. It resembles an extended version of the structure used by Bigalke et al. (2016) and the "micro census" structure used in census11. In contrast, the mc18 uses a starting year 29 years later (1948) than the other two (1919) and ends two years later (2011 instead of 2009). In order to fill these gaps, the datasets are extrapolated where needed to make them fit. Additionally, the data in mc18 is clustered in slightly different intervals. These differences are corrected by assigning the overlapping portion of the interval to the designated time frame in the final data structure. Additionally, annual mean values of the most recent years are applied to further extrapolate the available data to fill also the recent time frame between 2011 and 2020. The final interval "2021 and later" is created as placeholder for future values and thus filled with null values. This step is mainly necessary to correctly initiate the model.

From a statistician's point of view, the chosen clustering is unfavorable. Supposedly there is a reason for clustering logic used by Bigalke et al. (2016) and the "micro census structure" applied in census11. Possibly these clusters link to construction standards or energy efficiency standards. However, considering that this data structure in a way reflects the distribution of the building data over a time scale, the logic of aggregation can be very misleading when comparing the individual construction year groups. From a statistical standpoint the 10-year structure applied in census11 would be preferable because each group represented the same amount of time. The chosen final data structure, in contrast, contains clusters of different sizes: 7 years, 9 years, 11 years, 29 years. Consequently, there is little statistical insight in comparing one of the 29 years spanning cluster with the 7 years spanning cluster. This downside must be considered when handling and interpreting this data.

Another point of criticism is the considerable age of census11, which presents the core data set in the housing sector. However, it is the most recent dataset available with such high resolution in this sector. Fortunately, the housing sector is changing fairly slowly so that its age does not void the dataset and possible gaps can be filled without risking significant distortion.

Finally, the data on the available workforce is obtained from Destatis[9]. However, in the field of building constructions and renovation work are many different professions with overlapping skills and thus it is extremely difficult to attribute the individual professions to the different types of upgrade and add-on installation work that is to be considered in the model. Researching different carpentry websites, for example, suggested that carpenters are also capable to complete various insulation work, even installing windows and roof tiling. Thus multiple professions are pooled to perform similar tasks. Since neither the data nor other reports hint at realistic distributions, the following table 3.2.1-b depicts the chosen professions, their attribution to the specific installation work and their assumed time dedication to the specific tasks. A full overview of all main construction and finishing trades is given in Appendix C.5. These assumptions lead to an estimate on the potential available working

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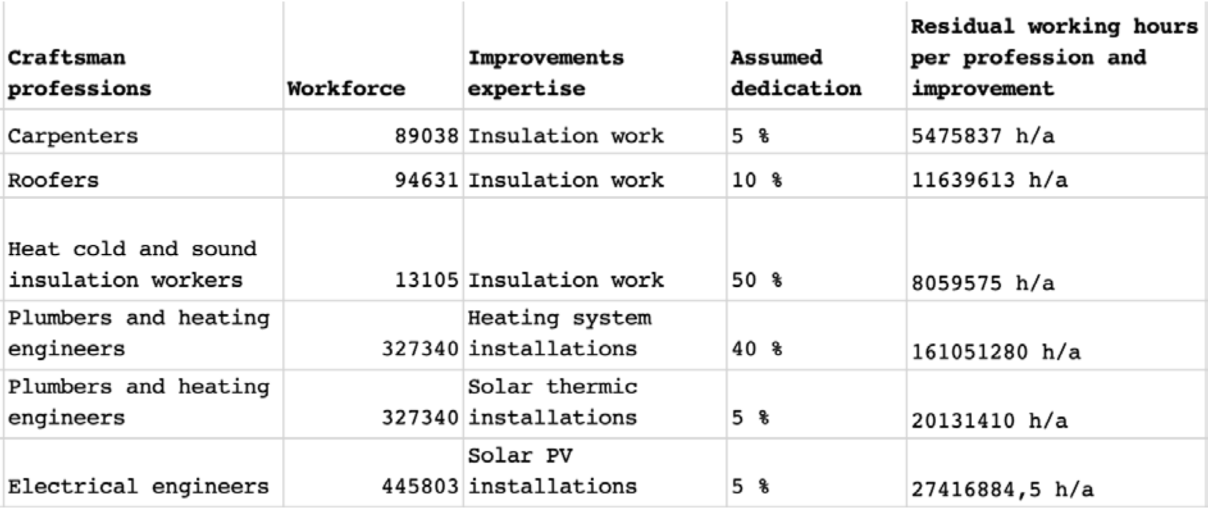
[9] destatis-53111

hours each profession can dedicate to the individual improvement installations. For this estimate, examining the report on the building industry by Statistisches Bundesamt (Destatis) (2020) revealed that construction workers on average work for 1230 hours per year.

Table 3.2.1-b: Workforce allocation



| Craftsman professions | Workforce | Improvements expertise | Assumed dedication | Residual working hours per profession and improvement |
|---|---|---|---|---|
| Carpenters | 89038 | Insulation work | 5 % | 5475837 h/a |
| Roofers | 94631 | Insulation work | 10 % | 11639613 h/a |
| Heat cold and sound insulation workers | 13105 | Insulation work | 50 % | 8059575 h/a |
| Plumbers and heating engineers | 327340 | Heating system installations | 40 % | 161051280 h/a |
| Plumbers and heating engineers | 327340 | Solar thermic installations | 5 % | 20131410 h/a |
| Electrical engineers | 445803 | Solar PV installations | 5 % | 27416884,5 h/a |

Due to profound assumptions underlying these estimates, the final available working hours per improvement work are each affected by an uncertainty variable that can be set to reduce the working hours between 0% and 100%.

**Data selection: Personal transportation sector**

The data on road-based transportation topics is collected and hosted by the Kraftfahrt-Bundesamt (KBA) in Germany. The main dataset that is used to initialize the distribution of cars by fuel type across the administration districts needs to be compiled from three different datasets of the KBA[10]. In order to obtain a dataset that allocates the existing car stock and new registrations segregated by ownership (private and non-private) and fuel type (petrol, diesel, HEV, PHEV, BEV) to the administration districts, the data needs to be compiled from different datasets provided by the KBA (see Appendix D).

Additional information on personal transportation performance is derived from the report authored by Radke (2019) from the KBA. Supplementary data is also found directly on the KBA[11] website, including data on national driving performance.

Additionally, the report by Fraunhofer ISE (2020) conveys various information that is relevant to the personal transportation sector. It suggests that about 15% of charging losses occur during EV charging, which is added to EV electricity consumption. Furthermore, the Fraunhofer ISE (2020) report gives detailed insights about the complexity and relationships between electricity production, housing, and personal transportation, which provided valuable background information.

Furthermore, data on public transportation, railway use and air travel statistics can be found at Destatis[12] and in the reporting of the German railway company Deutsche Bahn[13].

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[10] https://www.kba.de/DE/Statistik/Verzeichnisse/verzeichnisse_node.html;jsessionid=E7F58906F6E54025D826F4AB501141D0.live21301

[11] https://www.kba.de/DE/Statistik/statistik_node.html

[12] destatis-46100

[13] https://ir.deutschebahn.com/de/berichte/

### 3.2.2 Input uncertainty handling

The data quality and availability for this research quest is unexpectedly poor. As pointed out above, several data points need to be inferred, others imply even higher uncertainty.

**Least known unknowns**

Typically, societal behavior is most difficult to quantify as is the societal diversity most difficult to capture accurately. This is also the case here. The least known unknowns include consumption behavior that drive the transition, namely the preferences of buying electric vehicles, including the price elasticity of households regarding fuel price changes, and the propensity of buying housing upgrades and if so, which ones. The decision process in these three cases virtually represents a black box without indicators and extremely broad ranges of uncertainty. These uncertainties can best be represented with uncertainty variables that allow to significantly boost or limit the uncertain consumption behavior. This also implies, however, that there may be unknown unknowns that drive this behavior in the real world but are not represented in the model. Their potential existence must thus also be covered by the envisioned uncertainty variables.

**Systemic unknowns**

Further known unknowns, yet less profound, are linked to a systemic lack of data that unnecessarily increases the uncertainty of this study. Among others, this is the case for the improvement status of the building stock in Germany. Even though it is mandatory to evaluate energy efficiency metrics of buildings for the sale and renting of living space, it is unknown whether this data is systematically collected or not, at least it is not published. Table F in Appendix F gives an overview over a number of data inquiries made to governmental agencies and research organizations.  However, the Destatis response suggests that the German authorities do not collect more specific energy efficiency data. Also the organization CO2online could not help resolve this data gap. Thus an approximation solution was sought that uses other indicators to get similar insights. The data gap was finally overcome by, instead of using data on installed upgrades and add-ons and their performance, accepting that the initial data already accounts for unknown improvements hidden in the average energy consumption and approximating the outstanding gap to the average energy consumption of a fully improved building stock. This assumption infers that improvement benefits are shared between all building units of the same type in the same geographical area and does not clearly distinguish between buildings with and without improvement. Consequently, in the model also all buildings must pass through the improvement process. As each living space unit has five upgrade and two add-on options to improve, each improvement slightly increases the average building performance until all units are improved in all seven options.

Similarly with housing improvements, the KBA data also lacks information on the battery capacity and characteristic electricity consumption of electric vehicles. The cumulated battery capacity finally determines the upper limit of potential charging demand and presents a potential burden on the electricity sector. However, the effective energy consumption is more important in this case. Fortunately, an estimate on the average energy efficiency of EVs could be found in a report by ADAC[14].

Another case of uncertainty due to an unnecessary lack of data revolves around the available construction workforce and its specific allocation of working hours by type of work. As depicted above in table 3.2.1-b, the amount of working hours that can be attributed to the individual improvement work that is performed during construction and renovation required careful appraising. Hereto, for each profession the different possible tasks are considered and their assumed occurrence based on

[14] https://www.adac.de/rund-ums-fahrzeug/tests/elektromobilitaet/stromverbrauch-elektroautos-adac-test/

the assumed time each task consumes. Lacking reliable data, the values are only a rough estimate. Assuming that the estimates are rather optimistic, uncertainty variables are implemented through which the available working hours per field of improvement (insulation, heating system, electricity system) can be assigned a handicap.

#### Educated guesses

Similarly, the costs attributed to building improvements and car sales represent estimate average values, which may very well and with equal likelihood under- or overvalue the outstanding work. In this case, however, several indicators found during the literature and web search permit to assign price ranges to the individual options, which significantly lowers their uncertainty. The Appendix on Data Collection is a collection of all single data points that are collected and that help setting these ranges. Even though uncertainty variables are also attached to the cost variables, they are only secondary to the more impactful uncertainty on consumption decisions.

### 3.2.3 Policies specification data

The policies affecting the individual sectors were already presented during the literature review in chapter 2. The individual policy specifications are thus obtained from the publications of the responsible ministries. Most policies fall into the area of responsibility of the Federal Ministry of Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie, BMWi) and are thus published in its reports. This includes the overarching energy efficiency strategy 2050 (BMWi, 2019b), a summary of the building energy act (Gebäudeenergiegesetz, GEG) (BMWi, 2019a), the revision of GHG emission prices (BMWi, 2020), electric mobility (BMWi, n.d.). However, also other ministries publish relevant policy information, such as the Ministry for Environment, Nature Conservation and Nuclear Safety (BMU).

### 3.2.4 Conclusion on Data use

In summary, the used data is not at all fit to make predictions with this model. However, with the intention to assess system and policy robustness the data does not need to be perfectly accurate. On the contrary, the evaluation method is specifically designed to apply broad value ranges for such an assessment. The only requirement is that the data represents reality close enough so that the model can simulate the relative behavior as good as possible.

## 3.3 Model conceptualization

The three focal sectors are composed of several building blocks, thematic collections of variables that describe a sub-system. This section aims to outline each block in its essential characteristics, functions and underlying assumptions. These model aspects are derived from the case study outline, given the status quo and existing policies and strategies. Finally this conceptualization serves to specify the XLRM framework for further analysis in the next section.

### 3.3.1 Conceptualizing the Energy Sector

The energy sector is central for measuring the policy effects because the energy use from all focal sectors is collected here and converted into a GHG emissions estimate. The sector consists of four blocks, namely: electricity production composition, electricity demand aggregation, GHG emissions accounts, and energy and emissions prices.

### Electricity demand aggregation

The main block collects all energy consumption from within the model as well as from selected complementary external energy consumption values referring to the electricity need of non-focal sectors. Complementing the internal electricity consumption with these external values completes the picture on the total electricity use and environmental footprint, under the assumption that the external electricity consumption remains constant.

### Electricity production composition

Whereas other energy carriers are commonly burnt at the time and place their energy is needed (primary energy consumption), electricity is an intermediate carrier that is produced from primary energy sources mostly in a centralized fashion up to today. The second block handles the electricity production. It deals with the energy transition by incorporating decisions on technology phase-out, such as nuclear and coal power, and capacity building programs as well as balancing out the electricity demand on a macro level. This block is initiated from the last available distribution on the electricity mix in 2019 (AGEB, 2020a) and it takes as an input estimates on additions and reductions to the electricity mix as well as existing energy transition policies. The electricity production is complemented with an internal repowering meachanism for solar pv and wind power plants, replacing old units with newer and more powerful ones, based on reports by WindGuard (2018a), Rolink (2014) and Fraunhofer ISE (2020). The share of repowering activities has changed between 10% and 25% in the recent years. However, potentially it holds great value in the long term if existing sites will constantly be reused after the specific installation has reached the end of its lifetime. While currently each repowering iteration is accompanied by a significant increase in power output, this factor most likely gradually subsides over time as physical limits are reached (Deutsche WindGuard, 2018a, 2018b). Additionally, it is uncertain which fraction of old facilities is effectively replaced with new ones as this is up to a market mechanism. Simultaneously, the runtime of energy transition policies is very limited and their effectiveness more than questionable so that wind power capacity expansion can be derived from construction plans (Deutsche WindGuard, n.d.) but also these could still change as discussed by Modrakowski (2020) and Agora Energiewende and Wattsight (2020). For the medium term, the government published various targets for wind and solar pv power expansions up to the year 2050 but there is no evidence that these will be met, leading to another uncertainty in this building block.

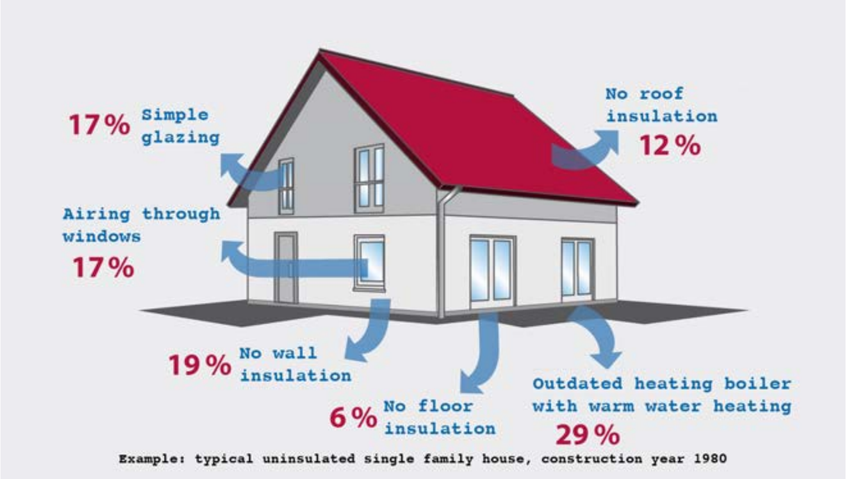


Figure 3.3.2-a: Energy loss potential per building component. Based on BDEW, n.d.

Furthermore, this block is connected to the demand of electricity and takes any supply deficit to add new electricity capacity to the production stock. The type of production technology to be added is based on a most recent historic distribution average excluding nuclear and coal power based on AGEB (2019a) data. The data shows extraordinarily high geothermal energy installations, which could possibly not be maintained but were not compensated due to the lack of better indicators.

### GHG emissions accounts

Third, the GHG emissions block estimates the GHG emissions from the actual consumption per energy source in the model. Therefore the sectoral energy consumption is multiplied by the respective emissions characteristics based on the CO2-Calculator by the Bayrisches Landesamt für Umwelt (LfU) (2018) and then aggregated per sector. Further, all emissions are summed in the core outcome value "GHG emissions from selected sectors combined" and are also presented as a relative improvement compared to the respective benchmark emissions in 1990, found in the UBA trends table by Gniffke (2019) and estimated from the Kraftfahrt-Bundesamt (2020) and Statistisches Landesamt Baden-Württemberg (2020) data.

### Energy and emissions prices

Finally, the fourth block concerns energy and emissions prices that are relevant factors in other building blocks on the model. The prices for electricity and car fuels are based on historic prices (Fluessiggas1, n.d.; Strom-Report, 2020; "Elektroauto", n.d.; "Erdgas", n.d.) and simulate simple gains over time, where the electricity price is also influenced by the electricity supply balance. The GHG emissions price is a bit more complex and is initiated at the proposed starting price by the BMWi (2020). To some extent it accounts for the share of renewable energies of the total electricity production and follows the upper and lower boundary conditions set by the BMWi (2020).

Figure 3.3.2-b: Energy improvement potential per building component. Based on BDEW, n.d.

Table 3.3.2-a: Elements of "Households stock"

| | |
|---|---|
| Buildings stock | Building construction |
| Dwellings stock | Improvement demand from dwelling constructions |
| Households formation | Household electricity consumption |
| Living space stock | Living space energy consumption |

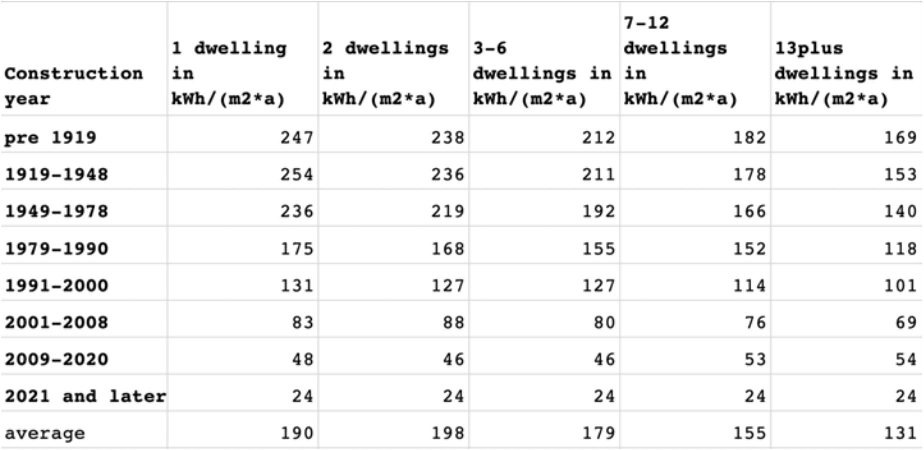
### 3.3.2 Conceptualizing the Housing Sector

The housing sector aims to represent the development of the housing stock and households as the key determinants for the energy consumption of the housing sector. In its core all its elements revolve around the propagation of living space and households and their relevant characteristics to derive the necessary energy metrics. Therefore it can be separated in three parts: the stock of buildings, dwellings, living space and households, the budget available to households and the improvement households can make to their buildings and dwellings.

Modelling the housing sector follows the basic idea that buildings, depending on the way they are constructed and which materials are used, have a specific heating energy demand characteristic. The characteristic is corellated to the construction years as the construction period determined the standards under which buildings were built. Additionally, the size of the house is an indicator for the average energy efficiency of a building. Especially living space built on top of each other, like in a large multi-family apartment complex, shows synergy effects neighboring dwellings have an insulating effect that reduces each others heating energy demand.

Furthermore, buildings have five main components that drive the demand for heating energy, as depicted in figure 3.3.2-a The four insulation components of floor, glazing, roof, and wall insulation determine how much heat dissipates to the outside. The fifth component, the heating system techology, determines which amount of the energy content that is contained in the energy source (fuel) can actually be used for heating the living space and drinking water and which amount is emitted and lost through the chimney. Additionally, also the airing behavior plays a role in energy losses as seen in figure 3.3.2-a but for now only the building structure is important. With this in mind, the BDEW (n.d.) developed a reference house model that depicts the base energy consumption with low insulation in comparison to high insulation as illustrated in figure 3.3.2-b.

Table 3.3.2-b: Heating energy demand characteristic value by building size and construction year



| Construction year | 1 dwelling in kWh/(m2*a) | 2 dwellings in kWh/(m2*a) | 3-6 dwellings in kWh/(m2*a) | 7-12 dwellings in kWh/(m2*a) | 13plus dwellings in kWh/(m2*a) |
|---|---|---|---|---|---|
| **pre 1919** | 247 | 238 | 212 | 182 | 169 |
| **1919-1948** | 254 | 236 | 211 | 178 | 153 |
| **1949-1978** | 236 | 219 | 192 | 166 | 140 |
| **1979-1990** | 175 | 168 | 155 | 152 | 118 |
| **1991-2000** | 131 | 127 | 127 | 114 | 101 |
| **2001-2008** | 83 | 88 | 80 | 76 | 69 |
| **2009-2020** | 48 | 46 | 46 | 53 | 54 |
| **2021 and later** | 24 | 24 | 24 | 24 | 24 |
| average | 190 | 198 | 179 | 155 | 131 |

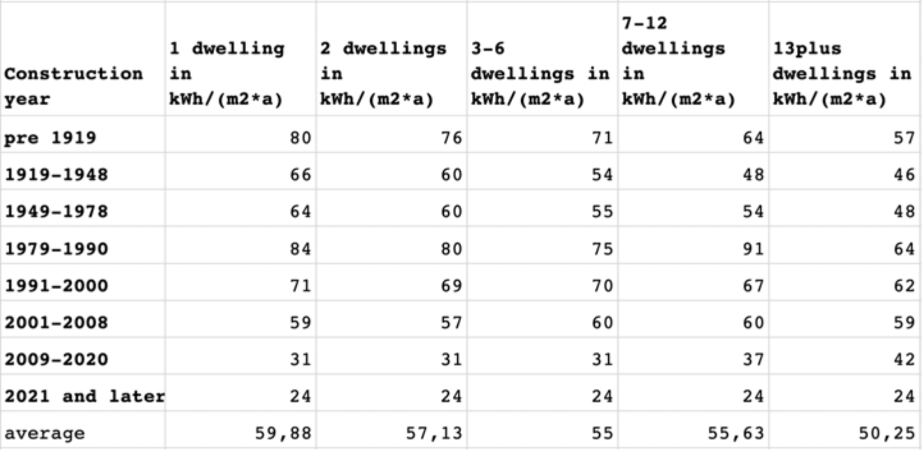
Own estimate

#### Households stock

The household stock aims to keep track of and improve the estimation of the housing stock and its properties, such as the number and size of buildings and dwellings, in order to obtain the governing values to connect to the available data on energy consumption and efficiency improvements. It is the foundation of all computations in the housing sector. The input data for the housing and dwelling stocks and households formation is obtained from different data services by the Statistisches Bundesamt (Destatis), including census data from 2011 (Statistisches Bundesamt, 2011) and 2018 (Statistisches Bundesamt, 2019) as well as complementary data from Genisis-Online[15] and Destatis[16] (Statistisches Bundesamt). Several external data points further help to estimate the consumption of insulation materials and working hours that are allocated to new building constructions. Finally, connecting also to estimates of electricity consumption per household by size and heating energy consumption per living space area of dwellings, the housing stock produces values on the final electricity and energy consumption per household and square-meter respectively, which are forwarded to the energy building block.

However, the energy characteristics of the housing sector are dynamic and change with the energy efficiency performance over time. The electricity consumption per household is difficult to reduce, instead it is expected that electricity consumption increases in the long term due to further electrification of household appliances and processes (Agora Energiewende and Wattsight, 2020; Bundesnetzagentur, 2020; Bundesverband Erneuerbare Energie, 2019). The estimates for 2030 electricity consumptions vary greatly, however, so that the long term outlook bears great uncertainty. Aside the generic electricity consumption increase, household electricity demand is further connected to and influenced by household solar pv installations and the charging of electric vehicles from the personal transportation building block. Where solar pv installations reduce the households final electricity demand, EV charging increases the demand.

Table 3.3.2-c: Residual energy characteristic values after improvements



| Construction year | 1 dwelling in kWh/(m2*a) | 2 dwellings in kWh/(m2*a) | 3-6 dwellings in kWh/(m2*a) | 7-12 dwellings in kWh/(m2*a) | 13plus dwellings in kWh/(m2*a) |
|---|---|---|---|---|---|
| pre 1919 | 80 | 76 | 71 | 64 | 57 |
| 1919-1948 | 66 | 60 | 54 | 48 | 46 |
| 1949-1978 | 64 | 60 | 55 | 54 | 48 |
| 1979-1990 | 84 | 80 | 75 | 91 | 64 |
| 1991-2000 | 71 | 69 | 70 | 67 | 62 |
| 2001-2008 | 59 | 57 | 60 | 60 | 59 |
| 2009-2020 | 31 | 31 | 31 | 37 | 42 |
| 2021 and later | 24 | 24 | 24 | 24 | 24 |
| average | 59,88 | 57,13 | 55 | 55,63 | 50,25 |

Own estimate, see appendix C.2

Additionally, households heating energy consumption is determined essentially by the insulation performance of the buildings, which is reflected in the average annual energy need per square-meter of living space. Starting off with an initial distribution of energy consumption per square-meter dependent on the construction year (age) and number of dwellings (size) of a building (table 3.3.2-b), the heating energy demand performance can be improved by upgrading the five building components: floor, glazing, roof, and wall insulation as well as the efficiency of the heating systems (Appendix C.1). The heating energy demand characteristic values in table X are estimated based on based on Bigalke et al. (2016) and insights from the European Energy performance of buildings directive (EU-EPBD)[17] as well as the Niedrig-Energie-Institut[18].

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[15] www-genisis.destatis.de

[16] www.destatis.de

[17] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

[18] https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/

Based on the initial energy characteristic, the output shows the business-as-usual (BAU) values of heating energy consumption and in a second step adds the upgrade improvements to show the final energy consumption from household heating based on the improvement ratio per building component (Appendix C.2). Upon completely upgrading a building, the final energy characteristics of buildings could be reduced significantly as shown in table 3.3.2-c.

Additionally, the heating energy demand can further be reduced by solar thermic add-on installations, which is further subtracted in the variable "total energy consumption from household heating after improvements".

The households stock building block also contains sub-blocks concerning building construction, living space stock, and improvement demand from dwelling constructions. These are perform intermediate functions bridging the initial data input and the needed data points to link the housing stock values with the specific energy consumption data points and preparing the dataset to be run through the household improvements building block.

### Household budget

The household budget aims to determine the spending propensity of households on possible energy efficiency improvements and therefore takes as an input the average yearly income per income group multiplied by the number of households per income group and maps budget restrictions and spending preferences over the available budget. Therefore it is assumed that the households that are able to save money for investments (whose monthly income is greater than EUR 1.500) on average are willing to spend 2,5% of their yearly income on long term improvement investments ("UNC base fraction of household income dedicated to improvement investments"). The detailed estimation of the household budget and the available income for non-essential spending is laid out in Appendix C.3.

Three types of possible energy efficiency improvements are distinguished, which are further explained below. Households can invest in building upgrades to increase the insulation performance, in building add-ons to produce their own energy, and in more efficient cars to reduce GHG emissions from transportation activities. The investment preferences of the three types are determined in relation to each other. Thus each type is assigned an assumed base preference value and an assumed value gain, which is complemented by the overall upgrade status of each type, considering that increasing shares of completed improvements decrease the remaining amount of outstanding improvement needs. Finally, the resulting relative preference distribution is applied to the "final disposable yearly income for improvement investments" resulting in the yearly available budget per improvement type from which the maximum achievable amount per year is derived. The outcomes are then forwarded as inputs to the household improvement building block and the new car registrations building block as part of the transportation sector, which are presented below.

NOTE shortcoming/limitation: The improvement mechanism takes the total available budget from all income groups combined. This missing distinction between the budgets allows the disproportionately large budget for investments of high income households to also be treated as an assumed budget available to lower income households. It makes a significant difference if all households share a common budget as opposed to each income group being limited to its own budget due to the asymmetric distribution of available means (finances) and obligations (the work needed to be done). The uneven distribution of income (Appendix C.3, Table C.3.2) is further amplified by similarly uneven distribution of the share of available net income that the income groups are assumed to be able to spend on non-essential consumption (Appendix C.3, Table C.3.3). As a result, over 82% of the budget estimated to be available for improvements is earned by the highest income group (Appendix C.3, Table C.3.4) In contrast, the need to improve a household's energy consumption seems to be rather evenly distributed as the rich and the poor alike occupy energy efficient and energy intensive living space.<<<

### Household improvements

The residual cumulative available household budget per annum is combined with an estimate of the total living space area that needs improving in the household improvements building block. The household improvements considered here are upgrades and add-ons to buildings. Upgrades indicate improvements to the essential structure of buildings that increase their passive efficiency, namely floor insulation, glazing, roof insulation, and wall insulation as well as heating system upgrades. Add-ons on the other hand refer to additions that can be made to the buildings' structure and more actively improve its efficiency. A variety of possible add-ons can be thought of, yet the most common in private households are photovoltaic (solar pv) and solar thermic installations that use solar power as well as environmental heat installations that use near-surface environmental heat. However, data on add-on installations in Germany is very scarce so that only solar power add-ons can be considered; the data on geothermal installations is not sufficient ->limitation.

The household improvements building block is further divided into four elements. First, there are a few intermediate supporting elements, such as improvement prices development and the very rough conversion estimate of living space area to improvement amount potential per improvement component. The prices of upgrades and add-ons follow the basic idea that learning-by-doing and economies of scale will lead to price reductions over time. The reduction was set to 0,2% p.a. of the actual price, whereas the used initial upgrade and add-on prices are shown in **Table 2 - household improvement prices.** In order to fit into the model structure, each price needed to be estimated in relation to square-meters of living space, which is the model's basic calculative unit in the housing sector. Such conversion undoubtedly produce estimation errors but for the sake of simplicity could not be avoided. The price estimates are joined with the previous budget estimates in order to obtain an upper limit on the amount of improvements per year. (see Appendix C.2 Upgrades / C.4 Add-ons on Improvements)

Second, aside from the limiting price to budget ratio, also the workforce sets a limit on the maximum amount of upgrades that can be achieved per year. Hereto the active workforce with the right qualifications is considered and distributed to the different upgrade and add-on installation activities. The available amount of working hours for improvement activity is initially reduced by an estimate of the working hours consumed by building constructions. Equally to the financial side, also the available working hours are divided by the time needed per installed square-meter and type of improvement, which returns an estimate of the maximum possible area that can be covered with the available working hours. The underlying assumptions and intermediate estimates that led to the final available working hours are outlined in the Appendix C.5.

Finally, these estimates are fed into the core improvement mechanisms in the housing sector. The process of improving households is separated for upgrades and add-ons but the structure and function is the same. Both take as inputs the initial total area that needs improvements and transfers it at the rate determined by an improvement function to the collection of completed improvements, which presents to output for further use. As mentioned before, the improvement function is mainly driven by the limits set by the annual budget and working hours per improvement type. The output values are then used to estimate the effective efficiency contribution with regard to housing upgrades as outlined in Appendix C.2 and the energy production capacity (electricity or heat) with regard to the housing add-ons as outlined in Appendix C.4. The housing upgrades also include heating systems, which vary significantly in energy efficiency and GHG emissions depending on the technology used. Therefore, the upgrades element also includes a process of replacing the existing distribution of heating system technology with a new, more sustainable distribution. The transition function in this case mirrors the transition amount of heating system upgrades processed in the general upgrades element. Also the budget and workforce factors are not considered in this step because they were already accounted for previously. However, the output of the heating systems element is essential for estimating the "household heating system current net consumption per fuel type", which allows the GHG emissions of the household sector to be estimated in combination with the actual heating energy consumption performance. The actual heating energy consumption performance is the result of the initial household energy performance combined with the efficiency improvements from upgrade installations. Additionally, also the solar thermic add-on installations reduce the final heating energy consumption. The solar pv add-on installations on the other hand reduce the electricity consumption of households, as mentioned above.

### 3.3.3 Conceptualizing the Personal Transportation Sector

The personal transportation sector finally aims to determine the energy consumption of personal transportation by linking personal mobility statistics to transportation modes in combination with fuel prices and consumption. The output of this sector not only accumulates energy consumption values of transportation means for the final GHG emissions estimate but also contributes to the accuracy of the electricity consumption of the housing sector. In order to achieve the desired output, the sector is structured in three blocks.

The starting point is set by the building block "Personal transportation demand and mode preferences", which is used to take the initial data on personal transportation demand, estimate its development over time and further apply a distribution of transportation mode preferences in order to determine the personal transportation demand for the different transportation modes. Derived from the system boundary definition, valid personal transportation modes include cars, public transportation (combining local and regional rail and road-based transportation), railways (referring to national railway transportation), national air travel, and bicycle transportation. The transportation mode preference are initiated with the last known distribution of passenger kilometer (pkm) but a mechanism is implemented that allows policies to affect the utility of the different transportation modes and thus alter the distribution over time.

The outcome of the "Personal transportation demand and mode preferences" block is then split up. Since this study focuses on household behavior change with the car as the bogeyman in the energy transition, the demand for car transportation is separated and prepared for more detailed simulation in the building block "Personal transportation by car". The outcome for other modes of transportation are immediately forwarded to the building block "Energy consumption from personal transportation", where their energy consumption characteristic is determined. Hereto their transportation performance statistics are transformed into general energy consumption. Aside from the transportation by car also public transportation, which includes a large autobus fleet, and air travel produce direct GHG emissions. However, recognizing the increased trend towards electrification in both sectors as presented during the literature review (2.1.3), they are additionally influenced by an electrification mechanism.

The "Personal transportation by car" building block is slightly more elaborate. The goal here is to look into different approaches to reduce the GHG emissions of the car fleet. The car fleet, distinguished by fuel type, is recorded in a general stock value. Petrol, diesel, gas, hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) are considered under different fuel types, even though the last three technically refer to entire drive systems. The fossil fuel based fuel types (petrol, diesel, gas and HEV) can also collectively be called combustion engine vehicles (CEV), whereas PHEV and BEV are summarized as electric vehicles (EV). HEV and PHEV are further assumed to be fueled with petrol for their non-electric part. Furthermore, the car fleet stock is filled by a logic propagating new car registrations and their distribution to the different fuel types. The "new car technology preferences" logic determines the final distribution of fuel types among new car registrations.

The preference logic itself is essentially driven by economic calculation as this was identified as the main driver of consumer behavior in chapter 2.2 (policy dimensions). However, several scholars also highlighted that consumers frequently act irrational and that purely economic incentives are insufficient (Storm, 2017). Nonetheless, the economic component is easily to quantify and implement in the model structure and therefore presents the foundation of this mechanism. The economic rationale is presented by the "car technology lifetime cost factor", which estimates the preferences of the car technologies (fuel types) by their respective lifetime cost. Additionally, the economic preference setting is complemented by an uncertainty factor that represents the consumers' irrational behavior. The variable "UNC new car pref objection against new technologies" therefore represents any divergent attitude towards the suggested change by reducing the preference value of any of the new technologies (gas, HEV, PHEV, BEV).

The lifetime costs of the technologies considers operation and maintenance costs as well as acquisition costs. Based on KBA[19] insights cars reach an average age of 18 years in Germany. Combining the expected age, yearly mileage, maintenance costs and fuel prices results an estimate on the lifetime costs per fuel type. The fuel prices refer to the price mechanisms previously introduced in the energy sector and also consider electricity prices for PHEV and BEV as well as GHG emissions prices in addition to fossil fuel prices for CEV. Aside from the uncertainties in fuel price development, equally the future acquisition costs and yearly mileage are linked to uncertainty factors. At the same time, policy levers representing the ongoing governmental support program for EVs are connected to the acquisition costs of EVs.

Finally, also the EV stock is linked to the aforementioned building block collecting the energy consumption from personal transportation. However, electricity use from charging EVs is handled separately. First, the ownership structure of the car fleet stock is taken into account in the previous step. This distinction enables to determine which the amount of EVs charging at home and at non-household charging stations. Again, there is uncertainty of which fraction of the electricity demand of privately owned EVs is actually charged at home. The amount of electricity demand from charging at home is then fed into the housing sector's household electricity demand as presented above. At last, the energy demand from non-household charging, the remaining fuel types, and the other modes of transportation is forwarded to the energy sector in order to sum up the total energy demand and GHG emissions from housing and personal transportation.

Additionally, a few more potential policy levers were identified. Considering the model structure, policies can influence either the overall personal transportation demand or more specifically alter the utility of the different modes of transportation.

## 3.3 Verification and Validation

Simulation models in the context of political decision making are targeted to help answer significant

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[19] https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html

questions and the insights drawn from such models can have severe consequences. Thus decision-makers are deeply concerned with the "correctness" and reliability of such models. Therefore verification and validation is a valuable step to ensure that the relationship between the model and its purpose are meaningful.

Verification commonly refers to ensuring the correct implementation of the computerized model. Validation further addresses the applicability of the model and seeks to confirm whether the model's accuracy corresponds to its intended range of application. Oreskes et al. (1994) underline that validity establishes a sense of legitimacy of and confidence in the model at hand. Typically, Sargent (2009) explains, "(…) performing model verification and validation, is generally considered to be a process and is usually part of the (total) model development process" (p.162). However, model verification and validation is a difficult undertaking.

This research applies a causal-descriptive model to evaluate its behavior. Barlas (1996) states that for such model "generating an 'accurate' output behavior is not sufficient model validity; what is crucial is the validity for of the internal structure of the model" (p. 185). Besides reproducing the real system's behavior the model structure must also serve to explain the generated behavior and suggest how the existing behavior could be changed (Barles, 1996). Yet, Barlas (1996) further notes that validating the internal structure of SD models is generally problematic due to the lack of formal tests for determining the consistent accuracy of the model to the real world counterpart structure with regard to the modelling purpose. Useful methods in such cases include validation through literature, experts, and historic data, among others as outlined by Sargent (2009).

Model concept validation is typically conducted through face validation during the modelling process, according to Sargent (2009). The previous section developed a model concept based on the findings during the review on the German energy transition. The concept is summarized in a flowchart to facilitate the concept validation.

Subsequently the computerized model needs to be tested if its structure and behavior are consistent with the reference system. Throughout the modelling process different techniques are applied to continuously verify the accurate model behavior. However, there is no benchmark for future behavior and in times like these on a topic that evaluates radical change, it seems paradoxical to apply historic data for verification and validation purposes other than for initiating the model. Nonetheless, historic data can be useful as a proxy for event validation in case of a "business-as-usual" (BAU) or no-change scenario. Significant indicators for the verification process are especially variables that produce outcome values for which comparable real world data could be found. Such include energy consumption and GHG emission values for housing and transportation.

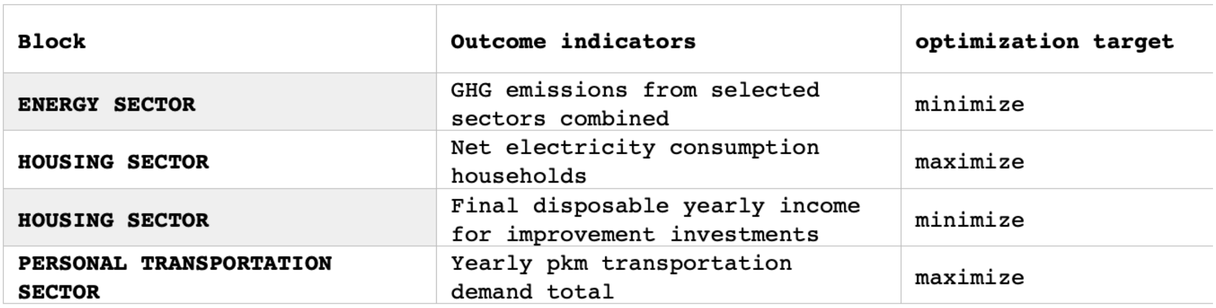
Additionally, fairly reliable indicators can be found for electricity use from households by 2030 and installed wind energy production capacity by 2030, which are used as a benchmark. Furthermore, the trends found in historic data are used to verify the remaining model behavior. The verification and validation indicators are depicted in Appendix E.1.

However, validating a transition model by testing its ability to "hold the current course" does not test its ability to accurately simulate change. Therefore, its ability to "get off course" in either possible direction is equally tested. This concludes the operational validity testing, the last step for verification and validation according to Sargent (2009).

Finally the model is set to be applied for policy analysis. In order to do so the framework under which the analysis is supposed to take place needs to be defined as well. The so-called XLRM-framework is useful in this case.

## 3.4 The Energy Transition Model

Table 3.4: Performance metrics / model outcomes



| Block | Outcome indicators | optimization target |
|---|---|---|
| **ENERGY SECTOR** | GHG emissions from selected sectors combined | minimize |
| **HOUSING SECTOR** | Net electricity consumption households | maximize |
| **HOUSING SECTOR** | Final disposable yearly income for improvement investments | minimize |
| **PERSONAL TRANSPORTATION SECTOR** | Yearly pkm transportation demand total | maximize |

These model outcomes represent the core qualities that govern the energy transition (table 3.4). They stand for deeper desires that can be attributed to citizens. The main priority for policy-makers and citizens alike is obviously to bring down GHG emissions. At the same time, however, other societal trends and desires stand may oppose this goal's trajectory.

Energy consumption has increased significantly over the last decades as Germany became an industrialized country and thus different sources expect household electricity consumption to increase between 10% to 20% over the next decade due to the ongoing digitalization trend, not to mention the expected side-effects of the energy transition (Agora Energiewende & Wattsight, 2020; Bundesnetzagentur, 2020; Bundesverband Erneuerbare Energie, 2019). An increase in electricity demand under the current electricity production regime, however, adversely effects the GHG emissions target.

Next, in parallel to the energy consumption trend increasing, so is citizens' general consumption of goods and services, as reflected in the trend of Germany's gross domestic product for example. Such consumer society may drive the economy but also reduces the amount that households decide to spend on long term investments such as building improvements or environmentally friendly cars. Investments like these directly compete with short term consumption desires and thus citizens are expected to minimize their spending on any kind of improvements.

Another one of those luxuries of life that citizens likely want to maintain or even expand is mobility. The globalization trend has become invaluable to society, not only in economic terms, and citizens greatly benefit from the ability to move and travel. Therefore, this analysis assumes the goal of maximizing mobility.

Additionally, the definition of levers and uncertainties can be found in Appendix E.2.

## 3.5 Evaluation methods

As pointed out in section 2.4.3, the evaluation will be based on a manual evaluation of the model behavior based on standard outcomes of reference scenarios.

### 3.5.1 Reference Scenario

The business-as-usual (BAU) scenario is the first of five reference points. It is characterized by applying no more policies as are already in place and assuming uncertainty values at either known historic estimate values or, if none are available, at 50% their possible setting. Since no one knows whether they will rather hit mild or strong, assuming the middle will cover a bit of both effects. The BAU scenario best reflects the situation today and therefore represents the status quo as reference to the other scenarios. The BAU scenario settings are listed in Appendix E.2.

### 3.5.2 Four extreme scenarios

After the BAU scenario, four combinations of applying levers and uncertainties come to mind in order to demarcate the possible best and worst outcomes.

1. All-off-scenario: X=0%, L=0%
2. All-on-scenario: X=100%, L=100%
3. Worst-case-scenario: X=100%, L=0%
4. Best-case-scenario: X=0%, L=100%

### 3.5.3 Experimentation designs

The experimentation designs are detailed in Appendix E.3. Two experiments are used to evaluate the policy options, characterized by the levers. The first is the base line experiment that was defined before (BAU). The second experiment is set to portray a strong effort by the government. In the energy sector, the levers are set to a repowering target of 90%, and there is high motivation to only build new renewable energy power plants instead of gas. Further the government levies a high price on fossil fuels for cars and sets no limit on GHG emission prices. EV-sales are also being supported with substantial subsidies of above EUR 10.000. At the same time policies are set to incourage spending on investments and increase the utility of alternative transportation services like public transportation and railways.

These two experiments are implemented in the simulation software for sensitivity analysis. This will take the specified levers/policies as fixed values in a number of simulation runs against changing values in the uncertainty ranges. The results then yield insight into the robustness of these policy sets.

Finally the outcomes of the extreme scenarios and the two experiment scenarios can be compared and evaluated for a final conclusion.

# 4 Experimentation and Results

This chaper is dedicated to portray the outcomes of the simulation runs and experiment outcomes, preparing the final discussion. The four defined outcome variables are applied to evaluate the policy performances as these are best equipped to qualify the performance as discussed above.

## 4.1 Outcomes of the extreme scenarios

Figure 4.1-a: GHG emissions performance

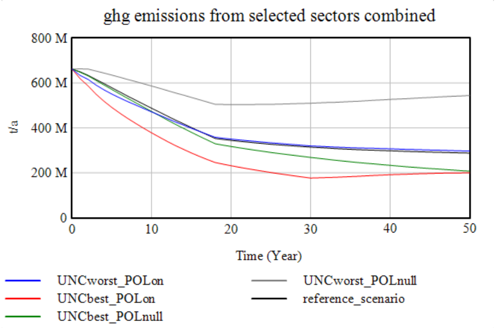
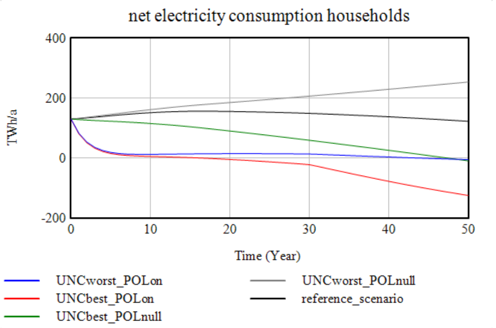


Figure 4.1-b: Household electricity consumption



The scenario names indicate the qualities of settings. “UNCworst” in the graph name refers to the uncertainty variables being set to the worst values with regard to the outcomes. “UNCbest” means that uncertainties will behave most favorably. The policy levers are distinguished by “POLnull” for no policies implemented and “POLon” for policies active. For each of the outcome variables the for scenarios are displayed next to each other.

Figure 4.1 refers to the most important variable in the model and directly relates to the goal of reaching net zero carbon emissions by 2050.

Figure 4.1-c: Disposable income: improvements

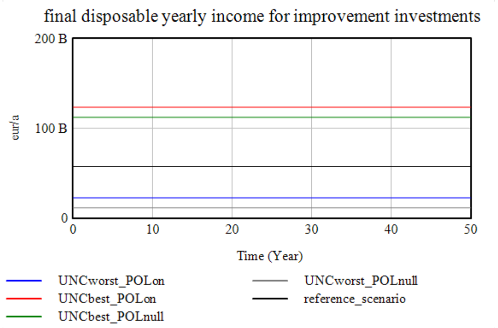


Figure 4.1-d: Energy intensity of transportation

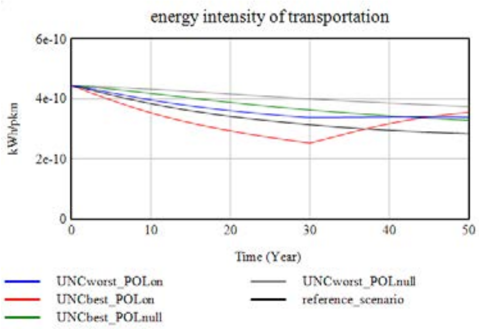


Figure 4.2.1-a: GHG emissions performance

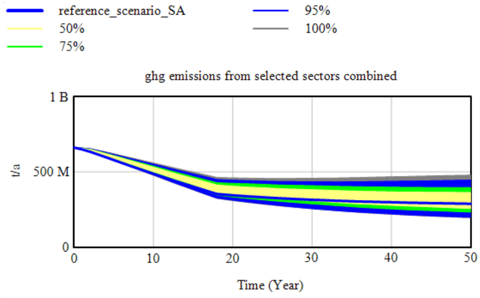


Figure 4.2.1-b: Household electricity consumption

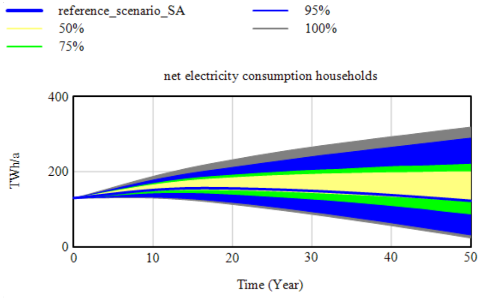


Figure 4.2.1-c: Disposable income: improvements

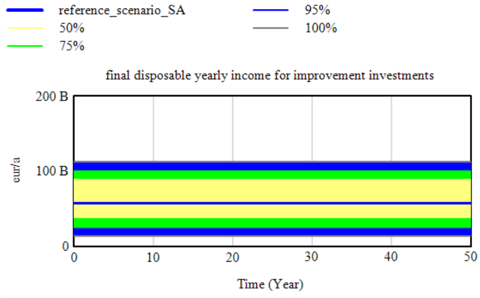
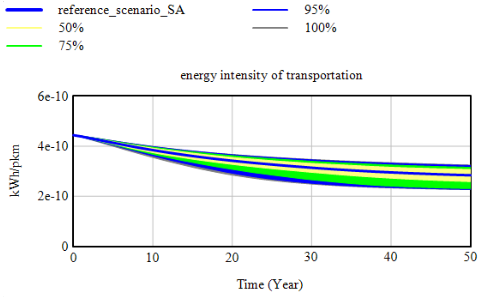


Figure 4.2.1-d: Energy intensity of transportation



## 4.2 Outcomes of the Sensitivity Analysis

### 4.2.1 Experiment 1 (BAU)

### 4.2.2 Experiment 2

Figure 4.2.1-a: GHG emissions performance

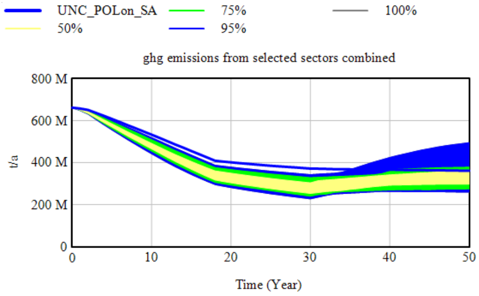


Figure 4.2.1-b: Household electricity consumption

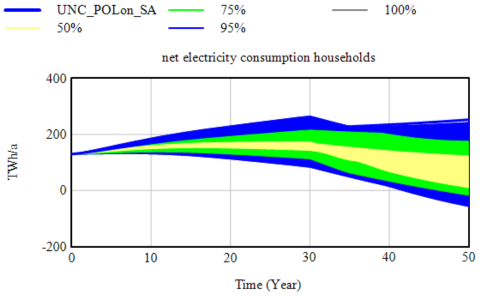


Figure 4.2.1-c: Disposable income: improvements

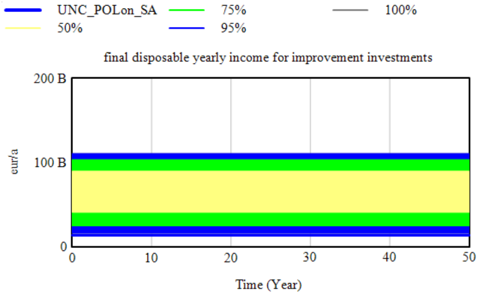
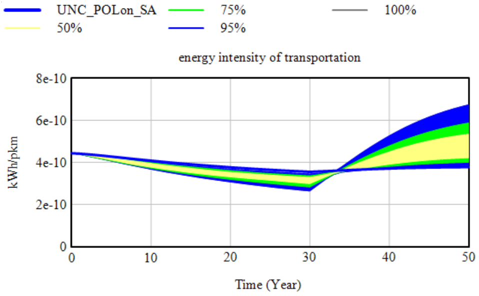


Figure 4.2.1-d: Energy intensity of transportation



# 5 Discussion

The energy transition, just as climate change or any of the other 17 Sustainable Development Goals (SDG) (UNFCCC, n.d.), poses a problem that cannot be satisfied with a simple straight answer as illustrated at the beginning of this work (Radosavljevic, 2019). Subsequently, systematically capturing the problem in a model is equally difficult. This section reviews the current state of the literature to first summarize the approaches to decision making in an uncertain environment, second portray the dimensions and choices involved related to modelling the energy transition and third discuss the available modelling formalisms for such a task.

# 6 Conclusion

First of all, the insights are very limited. Not only is the modelling approach in general only an abstraction of the real world and can only statistically approximate what could happen but also the lack of sufficient simulation capacity severely crippled this research's undertaking.

With regard to the main research question, the model outcomes suggest that there is a tough change to bring the Housing and Transportation sectors in Germany down to desired GHG emission levels. However, the phase-out of heavy emissions technologies such as coal fired power plants do a great deal to reducing the carbon footprint of electricity consumption. Also the move to electric vehicles has this potential. However, the effort seems a lot more demanding with today over 47 million registered fossil fuel powered personal vehicles. The financial incentive on EVs seems very important, especially the direct subsidies on sales prices play a major role in this modelling concept. Comparing fuel prices on the other hand does not seem to make a great difference, unless the premium on fossil fuels should rise significantly, either through emissions taxation or other levies. Further more, the renovation efforts in the housing sector have the potential of making a significant impact as well. How households spend their income seems to be the driving factor here, as the workforce appears to have by far enough capacities. However, capturing the decision mechanism of household income spending in the model turned out to be very difficult. The lack of data for verification and validation on this issue further complicated the modelling process. All in all however, the outcomes also show that a combined effort strategy is favored over very selective policy measures. This reflects that all the sectors are strongly connected with each other and every element has its significant contribution to the problem. Only letting the government do the heavy lifting by investing in new energy sources without the citizens adjusting their behavior to alternative modes of transportation will not lead to a favorable outcome.

Moreover, this work presents an abundent collection of specifications, relationships and datapoints that enabled this thesis to come alive. Some contributed during the modelling process, others were crucial pieces of information during the conceptualization, and then a few were indispensible to initiate the model. The Appendix G hold an overview over the data points sorted by sector.

The remaining "unknowns" that the future holds could further be approached with dynamically adapting policy strategies as proposed by Haasnoot, Kwakkel, Walker, & ter Maat (2013). Societies constantly evolve and radical, unforeseeable changes happen all the time as propagated by Geels (2002, 2011). In consequence, policies' effectiveness and efficiency decreases over time. Some policies are also meant to become obsolete. The energy transition, however, is expected to take a long time and the underlying threat of climate change will undoubtedly occupy society and policy-makers for generations to come. Examples for adaptive policy-making are, among others, presented by the nuclear power policies following Fukushima incident or the government support program for EV deadline adjusted with Corona crisis. Translated to the energy transition, an adaptive strategy could include further investments into gas infrastructure for the short term followed by resolute divestments at a later stage. Thus further combining the approach at hand with dynamic adaptive policy making methods would be another future research prospect.

# Bibliography

# Appendices

# Bibliography

ADAC. (2010). Mobilität in Deutschland. Fakten & Argumente Kompakt. München: ADAC e.V. Retrieved from www.adac.de/verkehrs-experten

ADAC. (2016a). Freizeitverkehr. Fachinformation - Ressort Verkehr. Retrieved from www.adac.de

ADAC. (2016b). Zahlen, Fakten, Wissen. Aktuelles aus dem Verkehr. München: ADAC e.V. Retrieved from www.adac.de

ADAC. (2019). Elektroautos brauchen die Energiewende: Die Klimabilanz. Retrieved May 25, 2020, from www.adac.de

ADAC. (2020, January). Auf Autogas umrüsten? Der ADAC-Armortisationsvergleich. Retrieved from www.adac.de

ADAC. (2020, February 3). Dieselfahrverbot: Alle Fragen und Antworten. Retrieved July 1, 2020, from https://www.adac.de/verkehr/abgas-diesel-fahrverbote/fahrverbote/dieselfahrverbot-faq/

AG Energiebilanzen (AGEB). (2019a). Auswertungstabellen zur Energiebilanz Deutschland Daten für die Jahre von 1990 bis 2018. Retrieved from www.ag-energiebilanzen.de

AG Energiebilanzen (AGEB). (2019b). Energy Flow Chart for the Federal Republic of Germany in 2018. Available from www.ag-energiebilanzen.de

AG Energiebilanzen (AGEB). (2020a). Bruttostromerzeugung. Berlin. Available from www.ag-energiebilanzen.de

AG Energiebilanzen (AGEB). (2020b). Energieverbrauch in Deutschland im Jahr 2019. Berlin. Available from www.ag-energiebilanzen.de

Agora Energiewende & Wattsight. (2020). Die Ökostromlücke, ihre Strommarkteffekte und wie sie gestopft werden kann. Effekte der Windenergiekrise auf Strompreise und $CO_2$-Emissionen sowie Optionen, um das 65-Prozent-Erneuerbare-Ziel 2030 noch zu erreichen. Studie im Auftrag von Agora Energiewende.

Alcock, C. (2020, July 20). EAG Launches 70-Seat Hybrid-electric Regional Aircraft. AIN Online. Retrieved from https://www.ainonline.com/aviation-news/air-transport/2020-07-20/eag-launches-70-seat-hybrid-electric-regional-aircraft

Anderson, K., Peters, G., 2016. The trouble with negative emissions. Science 354, 182–183.

Auping, W. L., Pruyt, E., de Jong, S., & Kwakkel, J. H. (2016). The geopolitical impact of the shale revolution: Exploring consequences on energy prices and rentier states. Energy Policy, 98, 390–399. https://doi.org/10.1016/j.enpol.2016.08.032

Auping, W. L., Pruyt, E., & Kwakkel, J. H. (2015). Societal Ageing in the Netherlands: A Robust System Dynamics Approach. Systems Research and Behavioral Science, 32(4), 485–501. https://doi.org/10.1002/sres.2340

Bankes, S. C. (1993). Exploratory Modeling for Policy Analysis. Operations Research, 41(3), 435–449. https://www.jstor.org/stable/171847

Bankes, S. C. (2002). Tools and techniques for developing policies for complex and uncertain systems. Proceedings of the National Academy of Sciences of the United States of America, 99(3), 7263–7266. https://doi.org/10.1073/pnas.092081399

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. System Dynamics Review, 12(3), 183–210. https://doi.org/10.1002/(sici)1099-1727(199623)12:3<183::aid-sdr103>3.0.co;2-4

Barton, R. R. (2010). Simulation experiment design. In Proceedings of the 2010 Winter Simulation Conference (pp. 75–86).

Bayrisches Landesamt für Umwelt (LfU). (2018). Excel-Tabelle zur Berechnung der CO2-Äquivalent-Emissionen (CO2-Rechner). Bayrisches Staatsministerium für Umwelt und Verbraucherschutz. Retrieved from https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen

Better, M., Glover, F., Kochenberger, G., & Wang, H. (2008). Simulation optimization: Application in risk management. International Journal of Information Technology & Decision Making, 7(4), 571–587.

BDEW. (2020). Energiemarkt Deutschland 2019. Retrieved from www.bdew.de/service/publikationen/bdew-energiemarkt-deutschland-2019/

BDEW. (n.d.). Infografiken Gebäudetechnik. Retrieved July 1, 2020, from www.bdew.de/service/daten-und-grafiken/infografiken-gebaeudetechnik/

Bhattacharyya, S. C., & Timilsina, G. R. (2010). A review of energy system models. International Journal of Energy Sector Management, 4(4), 494–518. https://doi.org/10.1108/17506221011092742

Bigalke, U., Armbruster, A., Lukas, F., Krieger, O., Schuch, C., & Kunde, J. (2016). dena Gebäudereport 2016: Statistiken und Analysen zur Energieeffizienz im Gebäudebestand. Berlin. Retrieved from www.dena.com

Bloch, R., Ehlers, K., Hofmeier, M., Nabel, M., Pfeffer, H., Scholz, S., & Wittenberg, J. (2019). Nachhaltigkeit im Ackerbau: Eckpunkte für eine Ackerbaustrategie. Bonn: Bundesministeriums für Umwelt Naturschutz und nukleare Sicherheit (BMU). Retrieved from www.bmu.de/downloads

BMU Arbeitsgruppe IK III 1. (2018). Klimaschutzbericht 2017: Zum Aktionsprogramm Klimaschutz 2020 der Bundesregierung. Berlin: Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). Retrieved from www.bmu.de/publikationen

BMU-Division IK III 1, Welke, M., Weiß, M., & Tibbe, T. (2018). Climate Action in Figures: Facts, Trends and Incentives for German Climate Policy 2018 edition. Berlin: Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU). Retrieved from www.bmu.de/publikationen

Bovermann, P. (2020, July 3). Vergoldete Dreckschleudern. Süddeutsche Zeitung. Retrieved 2020-07-13 from https://www.sueddeutsche.de/

Bundesministerium für Umwelt, Naturschutz Bau und Reaktorsicherheit (BMUB). (2014). Aktionsprogramm Klimaschutz 2020: Kabinettsbeschluss vom 3. Dezember 2014. Berlin. Retrieved from http://www.bmub.bund.de/service/publikationen/downloads/details/artikel/aktionsprogramm-klimaschutz-2020/

Bundesministerium für Umwelt, Naturschutz Bau und Reaktorsicherheit (BMUB). (n.d.). Begonnene und beschlossene Klimaschutzaktivitäten von gesellschaftlichen Akteuren. Retrieved from www.bmu.de/aktionsprogramm-klimaschutz

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). (n.d. a). Eckpunkte für das Klimaschutzprogramm 2030. Retrieved from www.bmu.de/downloads

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). (n.d. b). Leitlinien für die Wiederbewaldung in Deutschland. Retrieved from www.bmu.de/downloads

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). (2007). Eckpunkte für ein integriertes Energie- und Klimaprogramm. Retrieved from http://www.bmu.de/klimaschutz/downloads/doc/39875.php

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). (2016). Klimaschutzplan 2050 - Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung (2nd ed.). Berlin: Publikationsversand der Bundesregierung. Retrieved from www.bmu.de/publikationen

Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU). (2019a). Eckpunkte zur Ausgestaltung eines nationalen Emissionshandels für Wärme und Verkehr. Retrieved from www.bmu.de/downloads

Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU). (2019b). Klimabilanz 2018: 4,5 Prozent weniger Treibhausgasemissionen.

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). (2019c). Klimaschutz in Zahlen: CO2-Bepreisung. Retrieved from www.bmu.de/publikationen

Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU). (2019d). Klimaschutzbericht 2018 zum Aktionsprogramm Klimaschutz 2020 der Bundesregierung. Retrieved from https://www.bmu.de/download/

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). (2019e). Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050. Retrieved from https://www.bundesregierung.de/breg-de/themen/klimaschutz/klimaschutzprogramm-2030-1673578

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). (2019f). Projektionsbericht 2019 für Deutschland gemäß Verordnung (EU) Nr. 525/2013. Retrieved from https://cdr.eionet.europa.eu/de/eu/mmr/art04-13-14_lcds_pams_projections/projections/envxnw7wq/Projektionsbericht-der-Bundesregierung-2019.pdf

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU). (2019g). Umwelt in die Algorithmen! Eckpunkte für eine umweltpolitische Digitalagenda des BMU. Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU). Retrieved from www.bmu.de/downloads

Bundesministerium für Wirtschaft und Energie (BMWi). (n.d.). Elektromobilität. Berlin. Retrieved on 2020-07-01 from https://www.bmwi.de/Redaktion/DE/Dossier/elektromobilitaet.html

Bundesministerium für Wirtschaft und Energie (BMWi). (2014). Nationaler Aktionsplan Energieeffizienz (NAPE): Mehr aus Energie machen: Ein gutes Stück Arbeit. Berlin. Retrieved from http://www.bmwi.de/BMWi/Redaktion/PDF/M-O/nationaler-aktionsplan-energieeffizienz

Bundesministerium für Wirtschaft und Energie (BMWi). (2014). Sanierungsbedarf im Gebäudebestand: Ein Beitrag zur Energieeffizienzstrategie Gebäude. Berlin. Retrieved from www.bmwi.de

Bundesministerium für Wirtschaft und Energie (BMWi). (2015). Energieeffizienzstrategie Gebäude: Wege zu einem nahezu klimaneutralen Gebäudebestand. Berlin. Retrieved from www.bmwi.de

Bundesministerium für Wirtschaft und Energie (BMWi). (2019a). Das neue Gebäudeenergiegesetz – kurz zusammen gefasst. Berlin. Retrieved from https://www.bmwi.de/Redaktion/DE/Downloads/G/gebaeudeenergiegesetz-zusammen-gefasst.pdf

Bundesministerium für Wirtschaft und Energie (BMWi). (2019b). Energieeffizienzsstrategie 2050. Berlin: BMWi. Retrieved from www.bmwi.de

Bundesministerium für Wirtschaft und Energie (BMWi). (2019c). Neues Energielabel für alte Heizungen. Berlin. Retrieved from www.bmwi.de

Bundesministerium für Wirtschaft und Energie (BMWi). (2020). Bundeskabinett beschließt höheren CO2-Preis, Entlastungen bei Strompreisen und für Pendler. Berlin. Retrieved from https://www.bmu.de/pressemitteilung/bundeskabinett-beschliesst-hoeheren-co2-preis-entlastungen-bei-strompreisen-und-fuer-pendle/

Bundesministerium für Wirtschaft und Technologie (BMWi). (2010). Energiekonzept: für eine umwelt schonende, zuverlässige und bezahlbare Energieversorgung. Berlin: Bundesministerium für Wirtschaft und Technologie (BMWi). Retrieved from www.bmwi.de

Bundesnetzagentur. (2020, June 26). Genehmigung des Szenariorahmens 2021-2035. Bonn: Bundesnetzagentur.

Bundesverband Erneuerbare Energie (BEE). (2019). Das „BEE-Szenario 2030" 65%. Berlin.

Box, G. E. P. (1976). Science and statistics. Journal of the American Statistical Association, 71(356), 791–799. https://doi.org/10.1080/01621459.1976.10480949

Brouwer, F., Avgerinopoulos, G., Fazekas, D., Laspidou, C., Mercure, J. F., Pollitt, H., Ramos, E. P., Howells, M. (2018). Energy modelling and the Nexus concept. Energy Strategy Reviews, 19, 1–6. https://doi.org/10.1016/j.esr.2017.10.005

Bryant, B. P., & Lempert, R. J. (2010). Thinking inside the box: A participatory, computer-assisted approach to scenario discovery. Technological Forecasting and Social Change, 77(1), 34–49. https://doi.org/10.1016/j.techfore.2009.08.002

Buttermann, H. G. (2020). Energieverbrauch in Deutschland im Jahr 2019. Berlin. Available from www.ag - energiebilanzen.de

Cariboni, J., Gatelli, D., Liska, R., & Saltelli, A. (2007). The role of sensitivity analysis in ecological modelling. Ecological Modelling, 203(1–2), 167–182. https://doi.org/10.1016/j.ecolmodel.2005.10.045

Carrington, D. (2017, September 20). Melting Arctic ice cap falls to well below average. The Guardian. Retrieved from https://www.theguardian.com/environment/2017/sep/20/melting-arctic-ice-cap-falls-to-well-below-average

Carrington, D. (2020, March 11). Polar ice caps melting six times faster than in 1990s. The Guardian. Retrieved from https://www.theguardian.com/environment/2020/mar/11/polar-ice-caps-melting-six-times-faster-than-in-1990s

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. Energy Research and Social Science, 37 (March 2018), 175–190. https://doi.org/10.1016/j.erss.2017.09.015

Climate Files (a). 1982 Memo to Exxon Management about CO2 Greenhouse Effect. Climate Files. Retrieved 2019-09-03 from www.climatefiles.com

Climate Files (b). 1988 Shell Confidential Report "The Greenhouse Effect". Climate Files. Retrieved 2019-09-03 from www.climatefiles.com

Coello Coello, C. A., Lamont, G. B., & van Veldhuizen, D. A. (2007). Evolutionary Algorithms for Solving Multi-Objective Problems. Evolutionary Algorithms for Solving Multi-Objective Problems (2nd ed.). New York, NY: Springer. https://doi.org/10.1007/978-0-387-36797-2

Conrad, B. (2020, January 3). Hier gibt es kostenlosen Nahverkehr. Auto Motor Und Sport. Retrieved from https://www.auto-motor-und-sport.de/verkehr/kostenloser-nahverkehr-uebersicht/

Crippa, M., Oreggioni, G., Guizzardi, D., Muntean, M., Schaaf, E., Lo Vullo, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J.G.J., Vignati, E., (2019). Fossil CO2 and GHG emissions of all world countries - 2019 Report, EUR 29849 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-11100-9, doi:10.2760/687800, JRC117610.

Crespo del Granado, P., van Nieuwkoop, R. H., Kardakos, E. G., & Schaffner, C. (2018). Modelling the energy transition: A nexus of energy system and economic models. Energy Strategy Reviews, 20, 229–235. https://doi.org/10.1016/j.esr.2018.03.004

Crotty, J. (2017). Are Keynesian Uncertainty and Macrotheory Compatible? Conventional Decision Making, Institutional Structures and Conditional Stability in Keynesian Macromodels. Capitalism, Macroeconomics and Reality, 39–71. https://doi.org/10.4337/9781784719029.00009

De Cian, E., Dasgupta, S., Hof, A.F., van Sluisveld, M.A.E., K.hler, J., Pfluger, B., van Vuuren, D.P., 2018. Actors, Decision-making, and Institutions in Quantitative System Modelling_*Technological Forecasting and Social Change*. 2018, 119480

DeFries, R., Edenhofer, O., Halliday, A., Heal, G., Lenton, T., Puma, M., … Ward, B. (2019). The missing economic risks in assessments of climate change impacts, (September), 1–15. Retrieved from www.pik-potsdam.de/

Després, J., Hadjsaid, N., Criqui, P., & Noirot, I. (2015). Modelling the impacts of variable renewable sources on the power sector : Reconsidering the typology of energy modelling tools. Energy, 80, 486–495. https://doi.org/10.1016/j.energy.2014.12.005

Deutsche WindGuard. (n.d.). Publications wind energy statistics. Retrieved July 1, 2020, from https://www.windguard.com/publications-wind-energy-statistics.html

Deutsche WindGuard. (2018a). Status of Land-based Wind Energy Development in Germany: Year 2018. Varel. Retrieved from www.windguard.com

Deutsche WindGuard. (2018b). Status of Offshore Wind Energy Development in Germany: Year 2018. Varel. Retrieved from www.windguard.com

Deutscher Bundesrat. (2020a). Entschließung des Bundesrates zur EEG-Reform: Ausbau der Erneuerbaren Energien voranbringen. Drucksache 212/20 (Beschluss). Köln: Bundesanzeiger. Available from https://www.bundesrat.de/DE/dokumente/dokumente-node.html

Deutscher Bundesrat. (2020b). Entwurf eines Gesetzes zur Änderung des Windenergie-auf-See-Gesetzes und anderer Vorschriften. Drucksache 314/20. Deutscher Bundesrat. Available from https://www.bundesrat.de/DE/dokumente/dokumente-node.html

Deutscher Bundestag. (2019a). Erhöhung des Elektrifizierungsgrads im deutschen Eisenbahnnetz. Drucksache 19/16019. Berlin. Retrieved from https://dipbt.bundestag.de/doc/btd/19/160/1916019.pdf

Deutscher Bundestag. (2019b). Gesetz über einen nationalen Zertifikatehandel für Brennstoffemissionen (Brennstoffemissionshandelsgesetz - BEHG). Bundesgesetzblatt Jahrgang 2019 Teil I Nr. 50. Retrieved from www.bmu.de/GE877

Deutscher Bundestag. (2019c). Gesetz zur Einführung eines Bundes-Klimaschutzgesetzes und zur Änderung weiterer Vorschriften (2019). Bundesgesetzblatt Jahrgang 2019 Teil I Nr. 48. Bonn: Bundesanzeiger. Retrieved from http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl119s2513.pdf

Die Bundesregierung der Bundesrepublik Deutschland. (2019). Unterrichtung durch die Bundesregierung: Umweltbericht 2019 - Umwelt und Natur als Fundament des sozialen Zusammenhalts. Drucksache 19/13400. Berlin. Retrieved from www.bmu.de/downloads/umweltberichte

EC COM, 2011. Energy Road Map 2050. Technical Report. COM (2011) 885 final. Available at: http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm.

E-Auto Kaufprämie Corona (2020): 9.000€ Förderung. (2020). Retrieved July 1, 2020, from https://www.meinauto.de/lp-abwrackpraemie

Electric aircraft. (n.d.). Retrieved July 1, 2020, from https://en.wikipedia.org/wiki/Electric_aircraft

Elektroauto. (n.d.). Wikipedia. Retrieved from https://de.wikipedia.org/wiki/Elektroauto#Deutschland

Elsawah, S., Pierce, S. A., Hamilton, S. H., van Delden, H., Haase, D., Elmahdi, A., & Jakeman, A. J. (2017). An overview of the system dynamics process for integrated modelling of socio-ecological systems: Lessons on good modelling practice from five case studies. Environmental Modelling and Software, 93, 127–145. https://doi.org/10.1016/j.envsoft.2017.03.001

Energie Wissen. (n.d.). KfW Effizienzhaus 100. Retrieved July 1, 2020, from https://www.energie-wissen.info/energiesparhaeuser/kfw-effizienzhaus-100.html

Energieeinsparverordnung (EnEV) vom 24. Juli 2007 (BGBl. I S. 1519), die zuletzt durch Artikel 257 der Verordnung vom 19. Juni 2020 (BGBl. I S. 1328) geändert worden ist (2007). Retrieved from https://www.bmwi.de/Redaktion/DE/Gesetze/Energie/EnEV.html

Energiesparen-im-Haushalt.de. (n.d.). KfW Effizienzhaus 100. Retrieved July 1, 2020, from https://www.energiesparen-im-haushalt.de/energie/bauen-und-modernisieren/hausbau-regenerative-energie/energieverbrauch/kfw-effizienzhaus-100.html

Enkhardt, S. (2017, November 6). BEE: Kohlestrom mit Erneuerbaren ersetzen. Pv Magazine. Retrieved from https://www.pv-magazine.de/2017/11/06/bee-kohlestrom-mit-erneuerbaren-ersetzen/

Epstein, J. M. (1999). Agent-based computational models and generative social science. Complexity, 4(5), 41–60. https://doi.org/10.1002/(SICI)1099-0526(199905/06)4:5<41::AID-CPLX9>3.0.CO;2-F

Erdgas. (n.d.). Wikipedia. Retrieved from https://de.wikipedia.org/wiki/Erdgas

EU bans old-fashioned light bulbs. (2009, September 1). BBC News. Retrieved from http://news.bbc.co.uk/2/hi/europe/8230961.stm

European Commission. (2018). Air quality: Commission takes action to protect citizens from air pollution. European Commission - Press Release, (May), 30–32. Retrieved from http://europa.eu/rapid/press-release_IP-18-3450_en.htm

Evans, S., & Hausfather, Z. (2018, October 2). Q&A: How “integrated assessment models” are used to study climate change. CarbonBrief. Retrieved on 02.10.2019 from https://www.carbonbrief.org/

Fahrradportal. (2019). Marktanteil von Elektrofahrrädern wächst auf 23,5 Prozent. Retrieved June 23, 2020, from www.nationaler-radverkehrsplan.de

Farand, C., & Russo, J. (2019, September 20). ' Four million ' join students in climate marches , building pressure on leaders. Retrieved from https://www.climatechangenews.com/2019/09/20/three-million-join-students-global-strike-climate-action/

Filatova, T., Polhill, J. G., & van Ewijk, S. (2016). Regime shifts in coupled socio-environmental systems: Review of modelling challenges and approaches. Environmental Modelling and Software, 75, 333–347. https://doi.org/10.1016/j.envsoft.2015.04.003

Flato, G., Marotzke, J., Abiodun, B., Braconnot, P., Chou, S. C., Collins, W., … Rummukainen, M. (2013). Evaluation of Climate Models. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, … P. M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 741–866). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. https://doi.org/10.1017/CBO9781107415324

Fluessiggas1. (n.d.). Flüssiggasumrechnung. Retrieved July 1, 2020, from https://www.fluessiggas1.de/fluessiggas_umrechnung_kwh_m3_liter_kg/

Fontaine, C. M., & Rounsevell, M. D. A. (2009). An Agent-based approach to model future residential pressure on a regional landscape. Landscape Ecology, 24(9), 1237–1254. https://doi.org/10.1007/s10980-009-9378-0

Forrester, J. W. (1990). Models and the Real World. D4171. MIT System Dynamics Group Literature Collection.

Franta, B. (2018, September). Shell and Exxon's secret 1980s climate change warnings. *Guardian*. Retrieved 2019-09-03 from: www.theguardian.com

Fraunhofer ISE. (2020). Aktuelle Fakten zur Photovoltaik in Deutschland. Retrieved from https://www.ise.fraunhofer.de/de/veroeffentlichungen/veroeffentlichungen-pdf-dateien/studien-und-konzeptpapiere/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf

Fuss, S., Canadell, J.G., Peters, G.P., Tavoni, M., Andrew, R.M., Ciais, P., Jackson, R.B., Jones, C.D., Kraxner, F., Nakicenovic, N., Le Quere, C., Raupach, M.R., Sharifi, A., Smith, P., Yamagata, Y., 2014. Betting on negative emissions. Nat. Clim. Chang. 4, 850–853.

Gabrel, V., Murat, C., & Thiele, A. (2014). Recent advances in robust optimization: An overview. European Journal of Operational Research, 235(3), 471–483. https://doi.org/10.1016/j.ejor.2013.09.036

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. Research Policy, 31(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions, 1(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Geels, F.W., Sovacool, B.K., Schwanen, T., & Sorrell, S., (2017a). Sociotechnical transitions for deep decarbonization. Science 357, 1242.

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017b). The Socio-Technical Dynamics of Low-Carbon Transitions. Joule, 1(3), 463–479. https://doi.org/10.1016/j.joule.2017.09.018

Germany to fall short of 2020 climate goals: report. (2019, February 6). Retrieved September 23, 2019, from https://p.dw.com/p/3CrlF

Gniffke, P. (2019). National Trend Tables for the German Atmospheric Emission Reporting 1990-2017. Dessau: Umweltbundesamt (UBA). Retrieved from http://www.umweltbundesamt.de/emissionen

Gotts, N. M., van Voorn, G. A. K., Polhill, J. G., Jong, E. de, Edmonds, B., Hofstede, G. J., & Meyer, R. (2019). Agent-based modelling of socio-ecological systems: Models, projects and ontologies. Ecological Complexity, 40(July 2017), 100728. https://doi.org/10.1016/j.ecocom.2018.07.007

Große Koalition einigt sich auf Klimaschutzpaket. (2019, September 20). Spiegel Online. Retrieved 20.09.2019 from www.spiegel.de

Haak, J. (2020, January 16). Kohleausstieg : Zu lange, zu zaghaft. Berliner Zeitung. Retrieved 2020-07-13 from https://www.berliner-zeitung.de/

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change, 23(2), 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Hackett, S. B., Moxnes, E., 2015. Natural capital in integrated assessment models of climate change. Ecological Economics 116 (2015) 354–361.

Halim, R. A., Kwakkel, J. H., & Tavasszy, L. A. (2016). A scenario discovery study of the impact of uncertainties in the global container transport system on European ports. Futures, 81, 148–160. https://doi.org/10.1016/j.futures.2015.09.004

Hamarat, C., Kwakkel, J. H., Pruyt, E., & Loonen, E. T. (2014). An exploratory approach for adaptive policymaking by using multi-objective robust optimization. Simulation Modelling Practice and Theory, 46, 25–39. https://doi.org/10.1016/j.simpat.2014.02.008

Heiman, S. (2019, May 21). CO2-Ausstoß und Klimabilanz von Pkw Inhaltsverzeichnis. Retrieved from https://www.co2online.de/klima-schuetzen/mobilitaet/auto-co2-ausstoss/

Heiman, S. (2019, August 16). Bahn oder Flugzeug? CO2-Emissionen im Vergleich. Retrieved from https://www.co2online.de/klima-schuetzen/mobilitaet/bahn-oder-flugzeug-der-vergleich/

Heizung.de. (n.d.). Der durchschnittliche Energiebedarf im Haus. Retrieved July 1, 2020, from https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/

Helgenberger, S. (2019, October 7). Mut zur Umsetzung. Zeit Online. Retrieved 2019-10-10 from www.zeit.de

Holden, E. (2020, April 25). Climate science deniers at forefront of downplaying coronavirus pandemic. The Guardian. Retrieved from https://www.theguardian.com/world/2020/apr/25/climate-science-deniers-downplaying-coronavirus-pandemic

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC. (2018). Summary for Policymakers. (V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, … T. Waterfield, Eds.), Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,. Geneva, Switzerland: World Meteorological Organization. https://doi.org/10.1017/CBO9781107415324

Jacobsson, S., Bergek, A., & Sandén, B. (2017). Improving the European Commission's analytical base for designing instrument mixes in the energy sector: Market failures versus system weaknesses. Energy Research and Social Science, 33(September), 11–20. https://doi.org/10.1016/j.erss.2017.09.009

Kanzleramtschef verteidigt CO2-Preis-Pläne. (2019, September 21). Retrieved on 21.09.2019 from www.faz.net

Kasprzyk, J. R., Nataraj, S., Reed, P. M., & Lempert, R. J. (2013). Many objective robust decision making for complex environmental systems undergoing change. Environmental Modelling and Software, 42(April), 55–71. https://doi.org/10.1016/j.envsoft.2012.12.007

Kelly, R. A., Jakeman, A. J., Barreteau, O., Borsuk, M. E., Elsawah, S., Hamilton, S. H., Henriksen, H. J., Kuikka, S., Maier, H. R., Rizzoli, A. E., van Delden, H., Voinov, A. A. (2013). Selecting among five common modelling approaches for integrated environmental assessment and management. Environmental Modelling and Software, 47, 159–181. https://doi.org/10.1016/j.envsoft.2013.05.005

KfW Bank. (n.d. a). Der KfW-Effizienzhaus-Standard für einen Neubau. Retrieved July 1, 2020, from https://www.kfw.de/inlandsfoerderung/Privatpersonen/Neubau/Das-KfW-Effizienzhaus/

KfW Bank. (n.d. b). Förderkredite und Zuschüsse für bestehende Immobilien. Retrieved July 1, 2020, from https://www.kfw.de/inlandsfoerderung/Privatpersonen/Bestandsimmobilie/Förderprodukte/Förderprodukte-für-Bestandsimmobilien.html

Kraftfahrt-Bundesamt (KBA). (2020). Verkehr in Kilometern - Inländerfahrleistung. Kurzbericht: Entwicklungen der Fahrleistungen nach Fahrzeugarten seit 2015. Retrieved August 11, 2020, from https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/vk_inlaenderfahrleistung/vk_inlaenderfahrleistung_inhalt.html?nn=2351604

Kruger, T., Geden, O., Rayner, S., 2016. Abandon hype in climate models. Guardian. ( http://refhub.elsevier.com/S0040-1625(18)30059-3/rf0150 );

Kunkel, C. (2019, November 6). Beerdigt endlich den Verbrennungsmotor. Süddeutsche Zeitung. Retrieved on 2020-07-07 from www.sz.de/1.4668332

Kwakkel, J. H. (2017). The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making. Environmental Modelling and Software, 96, 239–250. https://doi.org/10.1016/j.envsoft.2017.06.054

Kwakkel, J. H., Haasnoot, M., & Walker, W. E. (2016). Comparing Robust Decision-Making and Dynamic Adaptive Policy Pathways for model-based decision support under deep uncertainty. Environmental Modelling and Software, 86, 168–183. https://doi.org/10.1016/j.envsoft.2016.09.017

Kwakkel, J. H., & Pruyt, E. (2013). Exploratory Modeling and Analysis, an approach for model-based foresight under deep uncertainty. Technological Forecasting and Social Change, 80(3), 419–431. https://doi.org/10.1016/j.techfore.2012.10.005

Kwakkel, J. H., & Pruyt, E. (2015). Using System Dynamics for Grand Challenges: The ESDMA Approach. Systems Research and Behavioral Science, 32(3), 358–375. https://doi.org/10.1002/sres.2225

Kwakkel, J. H., & Yücel, G. (2014). An exploratory analysis of the dutch electricity system in transition. Journal of the Knowledge Economy, 5(4), 670–685. https://doi.org/10.1007/s13132-012-0128-1

Lambert, F. (2016, November 9). Norway keeps electric vehicle tax exemption until 2020, positions itself to stay EV leader. Electrek. Retrieved from https://electrek.co/2016/11/09/norway-keeps-electric-vehicle-tax-exemption-until-2020-positions-itself-to-stay-ev-leader/

Langhelle, O. (1999). Sustainable development: Exploring the ethics of our common future. International Political Science Review, 20(2), 129–149. https://doi.org/10.1177/0192512199202002

Lempert, R. J., Groves, D. G., Popper, S. W., & Bankes, S. C. (2006). A general, analytic method for generating robust strategies and narrative scenarios. Management Science, 52(4), 514–528. https://doi.org/10.1287/mnsc.1050.0472

Lempert, R. J., Popper, S. W., & Bankes, S. C. (2003). Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis. Academy of Management Learning & Education. Santa Monica, CA: RAND. https://doi.org/10.5465/amle.2005.19086797

Lenton, T. (2016). 5 Anthropocene. In Earth System Science (pp. 74–90).

Li, F. G. N., Trutnevyte, E., & Strachan, N. (2015). A review of socio-technical energy transition (STET) models. Technological Forecasting and Social Change, 100, 290–305. https://doi.org/10.1016/j.techfore.2015.07.017

Lieb, S. (2019, January). Elektrifizierung des städtischen Busverkehrs: Hier fahren E-Busse. Aio - Das Magazin Für Die Mobilität Der Zukunft. Retrieved on 2020-06-23 from www.aiomag.de

Lingeswaran, S., (2019). Redefining Integrated Assessment Models: An Exploratory Approach Towards Robust Climate-Economic Policies. Retrieved from: http://resolver.tudelft.nl/uuid:812be430-79fb-4900-a0e2-b0bc9c3d804b .

Lustgarten, A. (2020, July 23). The great climate migration. New York Times. Retrieved from https://www.nytimes.com/interactive/2020/07/23/magazine/climate-migration.html

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. Research Policy, 41(6), 955–967. https://doi.org/10.1016/j.respol.2012.02.013

McCormick, J. (2018). Environmental Politics and Policy. Palgrave.

Meadows, D., Randers, J., & Meadows, D. (2004). 2-3 The driving force: exponential growth. In Limits to Growth: The 30-year update (pp. 17-26-51–57).

Modrakowski, E. V. (2020). Economic Robustness of the On-Shore German Wind Energy Industry under Deep Uncertainty. Delft University of Technology.

Müller, H.-S. (2020). Gebäudeenergiegesetz (GEG 2020) beschlossen. Retrieved August 5, 2020, from https://energie-m.de/info/geg-2020.html

Müller, H.-S. (2020). Niedrigstenergiegebäude (nZEB - nearly zero-energy buildings) Umsetzung in Deutschland. Retrieved August 5, 2020, from https://energie-m.de/info/niedrigstenergiegebaeude.html

Nance, R. E. (1981). The Time and State Relationships in Simulation Modeling. Communications of the ACM, 24(4), 173–179. https://doi.org/10.1145/358598.358601

Niedrig-Energie-Institut. (n.d.). Das EnEV-Referenzgebäude. Retrieved July 1, 2020, from https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/

Nikolic, I., Lukszo, Z., Chappin, E., Warnier, M., Kwakkel, J., Bots, P., & Brazier, F. (2019). Guide for Good Modelling Practice in policy support. https://doi.org/10.4233/uuid

Nikolic, I., Warnier, M., Kwakkel, J., Chappin, E., Lukszo, Z., Brazier, F., … Palensky, P. (2019). Principles , challenges and guidelines ecology. https://doi.org/10.4233/uuid

Nordhaus, W. (2008). A Question of Balance: Weighing the Options on Global Warming Policies. Yale University Press, New Haven & London.

Nordhaus, W. (2014). Estimates of the social cost of carbon: concepts and results from the dice-2013r model and alternative approaches. Journal of the Association of Environmental and Resource Economists , 1 (1/2), 273–312.

Nordhaus, T., Shellenberger, M., & Blomqvist, L. (2012). The Planetary Boundaries Hypothesis. A Review of the Evidence, (June), 1–43. https://doi.org/10.13140/RG.2.1.2149.2649

Norsk elbil forening. (n.d.). Norwegian EV policy. Norsk Elbil Foreningforening. Retrieved from https://elbil.no/english/norwegian-ev-policy/

Mabey, N. (2019, September 24). Decoding the UN Climate Action Summit. Retrieved from https://www.e3g.org/library/decoding-the-un-climate-action-summit-unga

Oreskes, N., Shrader-Frechette, K., & Kenneth, B. (1994). Verification , validation , and confirmation of numerical mode. Science, 263(February), 641–646.

Osgood, N. (2009). Lightening the Performance Burden of Individual Based Models through Dimensional Analysis and Scale Modeling. System Dynamics Review, 25, 101–134.

Osterath, B. (2018, May 17). EU takes Germany to court over air pollution. Deutsche Welle. Retrieved 2020-07-10 from https://p.dw.com/p/2rhZY

Parth, C. (2019, August 9). Kostenloser Nahverkehr - Ohne Ticket wird nicht alles gut. Zeit Online. Retrieved from https://www.zeit.de/mobilitaet/2019-08/kostenloser-nahverkehr-oepnv-finanzierung-nachhaltigkeit-stadtverkehr/

Peters, G.P., 2016. The 'best available science' to inform 1.5°C policy choices. Nat. Clim. Chang. 6, 646–649. ( http://refhub.elsevier.com/S0040-1625(18)30059-3/rf0190 )

Pfenninger, S., Hawkes, A., & Keirstead, J. (2014). Energy systems modeling for twenty-first century energy challenges. Renewable and Sustainable Energy Reviews, 33, 74–86. https://doi.org/10.1016/j.rser.2014.02.003

Pfenninger, S., Hirth, L., Schlecht, I., Schmid, E., Wiese, F., Brown, T., … Wingenbach, C. (2018). Opening the black box of energy modelling: Strategies and lessons learned. Energy Strategy Reviews, 19, 63–71. https://doi.org/10.1016/j.esr.2017.12.002

Pietzcker, R. C., Ueckerdt, F., Carrara, S., Sytze, H., Boer, D., Després, J., Fujimori, S., Johnson, N., Kitous, A., Scholz, Y., Sullivan, P., Luderer, G. (2017). System integration of wind and solar power in integrated assessment models : A cross-model evaluation of new approaches. Energy Economics, 64, 583–599. https://doi.org/10.1016/j.eneco.2016.11.018

Pindyck, R. S. (2013, September). Climate Change Policy: What Do the Models Tell Us? Journal of Economic Literature , 51 (3), 860–872. Retrieved 2019-02-01, from http://pubs.aeaweb.org/doi/10.1257/jel.51.3.860 doi: 10.1257/jel.51.3.860

Pinzler, P. (2019, October 7). Die Regierung duckt sich weg. Retrieved on 07.10.2019 from www.zeit.de

Power-to-gas. (n.d.). Wikipedia. Retrieved July 1, 2020, from https://en.wikipedia.org/wiki/Power-to-gas

Presse- und Informationsamt der Bundesregierung. (2011). Bundesregierung beschließt Ausstieg aus der Kernkraft bis 2022. Retrieved 2020-07-13 from https://www.bundesregierung.de/Content/DE/StatischeSeiten/Breg/Energiekonzept/05-kernenergie.html

Presse- und Informationsamt der Bundesregierung. (2020). Von der Kohle hin zur Zukunft. Berlin. Retrieved 2020-07-13 from https://www.bundesregierung.de/breg-de/bundesregierung/bundeskanzleramt/kohleausstieg-1664496

Pruyt, E., Auping, W. L., & Kwakkel, J. H. (2015). Ebola in West Africa: Model-Based Exploration of Social Psychological Effects and Interventions. Systems Research and Behavioral Science, 32(1), 2–14. https://doi.org/10.1002/sres.2329

Quaile, I. (2012, December 6). Klimawandel lässt das Polareis schmelzen. Deutsche Welle. Retrieved from https://www.dw.com/de/klimawandel-lässt-das-polareis-schmelzen/a-16429185

Radke, S. (2019). Verkehr in Zahlen 2019/2020. Flensburg: Bundesministerium für Verkehr und digitale Infrastruktur. Retrieved from www.bmvi.de/viz

Radosavljevic, Z. (2019, August 23). Merkel speaks in favour of increasing EU's 2030 climate target to 55%. Retrieved on 23.09.2019 from https://www.euractiv.com/

Rauch, W. von. (2011, February 25). Wie viel Energie verbraucht ein E-Bike (Pedelec), was ist die CO2 Bilanz? Retrieved from www.eradhafen.de

Rigaud, K. K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., … Midgley, A. (2018). Groundswell. The World Bank. Retrieved from https://openknowledge.worldbank.org/handle/10986/29461

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a General Theory of Planning. Policy Sciences, 4, 155–169.

Rogge, K. S., & Johnstone, P. (2017). Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende. Energy Research and Social Science, 33(September), 128–137. https://doi.org/10.1016/j.erss.2017.10.004

Rolink, D. (2014, May 30). Windkraft : Nach 20 Jahren Laufzeit ist noch lange nicht Schluss. Top Agrar Online. Retrieved from https://www.topagrar.com/energie/news/windkraft-nach-20-jahren-laufzeit-ist-noch-lange-nicht-schluss-9372151.html

Rosenthal, M. J. (2018, December 11). The United States isn't the only country downplaying climate change. The Washington Post, pp. 11–13. Retrieved from https://www.washingtonpost.com/energy-environment/2018/12/11/united-states-isnt-only-country-downplaying-climate-change/?utm_term=.7b7e53222e99

Rotmans, J., 2006. Tools for integrated sustainability assessment: a two-track approach. Integ. Assess. Int. J. 6, 35–57

RP-Online. (2020, August 25). Bundesregierung räumt Windrad-Hürden aus dem Weg. RP-Online. Retrieved from https://rp-online.de/politik/deutschland/windenergie-bundesregierung-raeumt-windrad-huerden-aus-dem-weg_aid-52969213

Rueter, G. (2014, July 15). Aus für CO2-Abscheidung als Klimaretter ? Deutsche Welle. Retrieved from https://www.dw.com/de/aus-für-co2-abscheidung-als-klimaretter/a-16992345

Salter, J., Robinson, J., Wiek, A., (2010). Participatory methods of integrated assessment—a review. Wiley Interdiscip. Rev. Clim. Chang. 1, 697–717.

Sargent, R. G. (2009). Verification and validation of simulation models. In Proceedings of the 2009 Winter Simulation Conference (pp. 162–176). https://doi.org/10.4018/978-1-60566-774-4.ch004

Sauer, N. (2019, September 20). Germany announces host of new measures to bring down CO2. Retrieved September 23, 2019, from https://www.climatechangenews.com/

Schultz, S. (2019, October 6). Regierung schwächt Klimaschutzziele ab. Spiegel Online. Retrieved 2019-10-10 from www.spiegel.de

Schwanitz, V. J. (2013). Evaluating integrated assessment models of global climate change. Environmental Modelling and Software, 50, 120–131. https://doi.org/10.1016/j.envsoft.2013.09.005

Sorrell, S., & Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. Ecological Economics, 65(3), 636–649. https://doi.org/10.1016/j.ecolecon.2007.08.013

Statista. (2020). Anteil der Pelec/E-Bike-Nutzer an deutschen Radreisenden von 2014 bis 2019. Statista. Retrieved from www.statista.de

Statistisches Bundesamt. (2011). Zensus 2011. Available from https://ergebnisse.zensus2011.de

Statistisches Bundesamt. (2019). Wohnen in Deutschland: Zusatzprogramm zum Mikrozensus 2018. (Statistische Ämter des Bundes und der Länder, Ed.). Wiesbaden: Statistisches Bundesamt (Destatis). Retrieved on 2020-07-01 from www.statistikportal.de

Statistisches Bundesamt (Destatis) (Ed.). Genesis-Online. Accessed on 2020-07-01. **Datenlizenz by-2-0**. Retrieved from www-genisis.destatis.de

Statistisches Bundesamt (Destatis) (Ed.). Destatis. Wiesbaden: Statistisches Bundesamt (Destatis). Retrieved from www.destatis.de

Statistisches Bundesamt (Destatis). (2020). Ausgewählte Zahlen für die Bauwirtschaft Januar 2020. Retrieved from www.destatis.de

Statistisches Landesamt Baden-Württemberg (Ed.). (2020). Fahrleistungen im Straßenverkehr. Retrieved on 2020-07-01 from https://www.statistik-bw.de/Verkehr/KFZBelastung/v5c01.jsp

Stephan, B., Lee, I., & Kim, J. (2019). Crashing the Climate: How the Car Industry Is Driving The Climate Crisis. (C. Roberts, Ed.). Seoul, SK and Hamburg, DE: Greenpeace East Asia and Greenpeace Germany. Retrieved from www.greenpeace.org

Stern, N., 2016. Economics: current climate models are grossly misleading. Nature 407-409.

Storm, S. (2017). How the Invisible Hand is Supposed to Adjust the Natural Thermostat : A Guide for the Perplexed. Science and Engineering Ethics, 23(5), 1307–1331. https://doi.org/10.1007/s11948-016-9780-3

Strom-Report. (2020). Strompreiszusammensetzung 2019. Retrieved July 1, 2020, from https://www.strom-report.de/strompreise/strompreis-zusammensetzung/

Taleb, N. N. (2007). The Black Swan. New York, NY: Random House.

The costs of climate inaction. (2018). Nature, 561(7724), 433. https://doi.org/doi:http://dx.doi.org.ezproxy.uis.no/10.1038/d41586-018-06827-x

Theiding, L., & Landwald, E. (2019, April 18). Pro und Contra kostenloser ÖPNV - Sollte der Nahverkehr kostenlos sein? TAZ. Retrieved from https://taz.de/Pro-und-Contra-kostenloser-OePNV/!5589087/

Thiele, P. (2020, July 14). Top-Gehälter der deutschen Wirtschaft: Vorstände der DAX-Unternehmen verdienen etwas weniger. SWR Aktuell. Retrieved from www.swr.de/swraktuell/gehaelter-vorstandsvorsitzende-vorstaende-dax-100.html

Tsanova, T. (2020, August 27). Climeworks goes to Iceland for geothermal-powered CCS project. Renewables Now. Retrieved from https://renewablesnow.com/news/climeworks-goes-to-iceland-for-geothermal-powered-ccs-project-711431/

Übertragungsverlust. (n.d.). Retrieved July 1, 2020, from https://de.m.wikipedia.org/wiki/Übertragungsverlust

Umweltbundesamt (UBA) (Ed.). (2018, November 20). Hohe Kosten durch unterlassenen Umweltschutz: Eine Tonne CO2 verursacht Schäden von 180 Euro – Umweltbundesamt legt aktualisierte Kostensätze vor. Retrieved from https://www.umweltbundesamt.de/presse/pressemitteilungen/hohe-kosten-durch-unterlassenen-umweltschutz

Umweltbundesamt (UBA). (2020a). Energieverbrauch privater Haushalte. Retrieved July 14, 2020, from http://www.umweltbundesamt.de/daten/private-haushalte-konsum/energieverbrauch-privater-haushalte

Umweltbundesamt (UBA). (2020b). Vergleich der durchschnittlichen Emissionen einzelner Verkehrsmittel im Personenverkehr in Deutschland - Bezugsjahr 2018. Retrieved from http://www.umweltbundesamt.de/

Umweltbundesamt (UBA), & Bundesministerium für Wirtschaft und Energie (BMWi). (2018). Energieeffizienz in Zahlen: Entwicklungen und Trends in Deutschland 2018. (Umweltbundesamt (UBA), Fachgebiet I 2.4, & BMWi, Eds.). Berlin: Bundesministerium für Wirtschaft und Energie (BMWi). Retrieved from www.bmwi.de

United Nations. (2015). The Paris Agreement. https://doi.org/FCCC/CP/2015/L.9

United Nations. (2018). World 'Nearing Critical Point of No Return' on Climate Change, Delegate Warns, as Second Committee Debates Sustainable Development. Retrieved 2018-01-09, from https://www.un.org/press/en/2018/gaef3500.doc.htm

Victor, D., 2015. Climate change: embed the social sciences in climate policy. Nature 520 (7545), 27–29. ( http://refhub.elsevier.com/S0040-1625(18)30059-3/rf0265 )

van Dam, K. H., Nikolic, I., & Lukszo, Z. (2013). Agent-Based Modelling of Socio-Technical Systems. (K. H. van Dam, I. Nikolic, & Z. Lukszo, Eds.), Agent-Based Modelling of Socio-Technical Systems. Dordrecht: Springer. https://doi.org/10.1007/978-94-007-4933-7

van Rüth, P., Schönthaler, K., von Andrian-Werburg, S., & Buth, M. (Eds.). (2019). Monitoringbericht 2019 zur Deutschen Anpassungsstrategie an den Klimawandel: Bericht der Interministeriellen Arbeitsgruppe Anpassungsstrategie der Bundesregierung. Dessau-Roßlau: Umweltbundesamt.

van Sluisveld, M. A. E., Harmsen, M. J. H. M., van Vuuren, D. P., Bosetti, V., Wilson, C., & van der Zwaan, B. (2018). Comparing future patterns of energy system change in 2 °C scenarios to expert projections. Global Environmental Change, 50(April), 201–211. https://doi.org/10.1016/j.gloenvcha.2018.03.009

van Sluisveld, M. A. E., Hof, A. F., Carrara, S., Geels, F. W., Nilsson, M., Rogge, K., Turnheim, B., van Vuuren, D. P. (2018). Aligning integrated assessment modelling with socio-technical transition insights : An application to low-carbon energy scenario analysis in Europe. Technological Forecasting & Social Change, (October 2017). https://doi.org/10.1016/j.techfore.2017.10.024

van Vuuren, D.P., Lowe, J., Stehfest, E., Gohar, L., Hof, A. F., Hope, C., Warren, R., Meinshausen, M., Plattner, G-K., 2009. How well do integrated assessment models simulate climate change? Climatic Change (2011) 104:255–285 DOI 10.1007/s10584-009-9764-2

Verburg, P. H., Dearing, J. A., Dyke, J. G., Leeuw, S. van der, Seitzinger, S., Steffen, W., & Syvitski, J. (2016). Methods and approaches to modelling the Anthropocene. Global Environmental Change, 39, 328–340. https://doi.org/10.1016/j.gloenvcha.2015.08.007

Volkswagen AG. (2020). Bezüge des Vorstands. Wolfsburg. Retrieved from https://geschaeftsbericht2019.volkswagenag.com

Walberg, D. (2012). Typische Energieverbrauchskennwerte deutscher Wohngebäude. Kiel: Arbeitsgemeinschaft für zeitgemäßes Bauen e.V. Retrieved from https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf

Walker, W. E., Lempert, R. J., & Kwakkel, J. H. (2013). Deep Uncertainty. (S. I. Gass & M. C. Fu, Eds.), Encyclopedia of Operations Research and Management Science. Boston, MA: Springer. https://doi.org/https://doi.org/10.1007/978-1-4419-1153-7_1140

Watson, A. A., & Kasprzyk, J. R. (2017). Incorporating deeply uncertain factors into the many objective search process. Environmental Modelling and Software, 89, 159–171. https://doi.org/10.1016/j.envsoft.2016.12.001

Watts, J. (2019, July). 'No doubt left' about scientific consensus on global warming, say experts. *The Guardian*. Retrieved on 03.09.2019 from www.theguardian.com

Westermann, R., & Richter, C. (2018). dena Concise 2018 Building Report: Energy efficiency in the building stock – statistics and analyses. Berlin. Retrieved from https://www.dena.de/

White Jr., K. P., & Ingalls, R. G. (2009). Introduction To Simulation. In Proceedings of the 2009 Winter Simulation Conference (pp. 12–23). Retrieved from http://www.informs-sim.org/wsc11papers/124.pdf

Wo Diesel-Fahrverbote gelten oder drohen. (2019, July 23). Süddeutsche Zeitung. Retrieved from https://www.sueddeutsche.de/wirtschaft/fahrverbote-deutschland-ueberblick-1.4220563

Wuttke, S., Junker, S., & Winkler, S. (2017). Umsteuern erforderlich: Klimaschutz im Verkehrssektor - Sondergutachten November 2017. Berlin: Sachverständigenrat für Umweltfragen (SRU). Retrieved from www.umweltrat.de

Yilmaz, L., Taylor, S. J. E., Fujimoto, R., & Darema, F. (2014). PANEL: THE FUTURE OF RESEARCH IN MODELING & SIMULATION. In A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, & J. A. Miller (Eds.), Proceedings of the 2014 Winter Simulation Conference (pp. 2797–2811). IEEE.

Záboji, N. (2019, September 21). Ist das Klimapaket eine Mogelpackung? Frankfurter Allgemeine Zeitung. Retrieved 2020-07-13 from https://www.faz.net/-gqe-9rf7v

Zeigler, B. P., Praehofer, H., & Kim, T. G. (2000). Introduction to Systems Modeling Concepts. In B. P. Zeigler, H. Praehofer, & T. G. Kim (Eds.), Theory of Modeling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems (2nd ed., pp. 1–21). New York: Academic Press. https://doi.org/10.1016/b978-0-12-813370-5.00009-2

Zhang, M., Verbraeck, A., Meng, R., Chen, B., & Qiu, X. (2016). Modeling spatial contacts for epidemic prediction in a large-scale artificial city. Jasss, 19(4). https://doi.org/10.18564/jasss.3148

# Appendix A

## Collection of German energy transition policies

| Topic | # | Policy action | Direct effect | Potential side effects | Resulting model component |
|---|---|---|---|---|---|
| GHG emissions | **1** | **CO2 pricing relating to heating and transportation** | making the use of fossil fuels more expansive | switch to less GHG intensive fuels | assume a price on GHG emissions that links to fossil fuel use |
| GHG emissions | **2** | **ETS as instrument in sectors heat and transportation** | can increase the price of burning fossil fuels. may need minimum price setting | governments may need to drastically limit total certificates on the market over time | track fossil and REN technology share in system |
| GHG emissions | **3** | **minimum price in ETS** | limits supply of GHG certificates, lower bound on emissions price | may significantly increase fossil fuel prices and harm consumers | set minimum price for GHG emissions |
| relief of citizens and economy | **4** | **reduce electricity costs** | incentive to use electricity | 1. supplementing other energy source<br>2. reboundeffect | incentivize electric appliances |
| relief of citizens and economy | **5** | **increase fixed-rate allowance for long distance commuters** | incentivize long-distance car-commuting | 1. less switch to public transport<br>2. less incentive for public transport to improve service<br>3. relief financial burden on those relying on long-distance car travel | dampening switch from fossil cars to EV and from car to alternative transport modes |
| relief of citizens and economy | 6 | change housing subsidies in tenant law | ? | ? | not relevant |
| relief of citizens and economy | 7 | transfer efforts | ? | ? | not relevant |
| energy sector | **8** | **stepwise reduction until termination of coal-power in 2038** | decrease share of coal in electricity mix, GHG and particle emissions reduction | 1. need to replace electricity production capacity<br>2. electricity grid stability<br>3. loss of labor force expertise and location<br>4. minor coal price effect<br>5. electricity price effect | 1. linear reduction of electricity produced with coal until termination date<br>2. replacement of energy capacity with alternative sources |
| energy sector | **9** | **expansion of renewable energy to 65% share of the gross electricity consumption by 2030** | increasing renewable energy technology by 2030 | 1. GHG emissions reduction<br>2. electricity grid instability<br>3. labor force and material demand shift | 1. adding new and repowering existing renewable energy capacity<br>2. link electricity production characteristic to GHG emissions footprint |

| | | | | | |
|---|---|---|---|---|---|
| energy sector | **10** | **development and modernizing of CHP plants** | increased efficiency of gas/CHP plants | 1. prolongued lifetime CHP<br>2. limited GHG emissions reduction<br>3. continued gas infrastructure investments extends technology lock-in duration | maintain gas power plants as a viable alternative |
| energy sector | **11** | **convert heat-grids to renewable energy and unavoidable waste heat** | efficiency increase, GHG emissions reduction | ? | maintain district heating as a viable alternative |
| energy sector | 12 | reality laboratories of the energy transition | ? | ? | not relevant |
| energy sector | 13 | energy efficiency strategy 2050 | ? | ? | not relevant |
| energy sector | 14 | supporting measures for the energy transition | ? | ? | not relevant |
| energy sector | 15 | EU-cooperation | ? | ? | not relevant |
| energy sector | 16 | investment program: energy efficiency and process heat from renewable energy in the economy | energy efficiency gains | GHG emissions | not relevant |
| building sector | **17** | **tax relief program for energetic renovation of buildings** | building efficiency gain, consumer incentive | 1. demand for insulation materials (roof, glass, walls, floor)<br>2. demand for insulation installers<br>3. potential rebound effect | 1. renovation mechanism (roof, glass, wall, floor)<br>2. financial support for renovations<br>3. energy efficiency effect of household heating<br>4. material demand<br>5. labor demand |
| building sector | **18** | **financial support program for efficient buildings including replacement bonus for oil heating** | new building efficiency standard, replacing oil heating systems | demolition and reconstruction can decrease GHG emissions | 1. renovation vs new construction choice<br>2. replacement of oil heaters |
| building sector | 19 | financial support for serial renovations | building efficiency | GHG emissions | not relevant |
| building sector | 20 | energetic renovation of cities | none | none | not relevant |
| building sector | 21 | energy consulting and PR | awareness raising | ? | not relevant |
| building sector | 22 | examplary function of federal buildings | renovating governmental buildings as soon as possible | ? | not relevant |
| building sector | 23 | continuous development of energy standards | increase energy standards continually until near carbon neutrality and minimum energy use | | not relevant |

| | | | | | |
|---|---|---|---|---|---|
| building sector | **24** | **new constructions energy standard by GEG2020** | average of 45-60 kWh/m2 energy characteristic consumption of new constructions from 2021 | GHG emissions | implement change in characteristic energy consumption value for new buildings from 2021 |
| building sector | **25** | **renewal of GEG in 2024** | unknown. possible further decrease of energy characteristic consumption from 2026 | GHG emissions | implement change in characteristic energy consumption value for new buildings from 2026 |
| building sector | 26 | climate protection through urban development | ? | ? | not relevant |
| building sector | 27 | development of the innovation program Future Building | ? | ? | not relevant |
| building sector | 28 | energy efficiency strategy 2050 | ? | ? | not relevant |
| transportation sector | **29** | **increase utility of rail passenger traffic** | 1. increased reliability, capacity<br>2. increasing passenger numbers | 1. improved image<br>2. reducing car and air travel | 1. utility gain of railways<br>2. linking railway gains to public transport, biking and walking<br>3. switch from car/ air travel to rail passenger transport |
| transportation sector | **30** | **increase utility of public transport** | 1. increased reliability, capacity<br>2. increasing passenger numbers | 1. improved image<br>2. reducing car and air travel | 1. utility gain of public transport<br>2. linking railway gains to public transport, biking and walking<br>3. switch from car travel to public transport |
| transportation sector | **31** | **expansion of cycle-tracks, bike parking space, and improving framework conditions** | 1. decreased travel time for cycling<br>2. improved connectivity | 1. improved image<br>2. potential adverse effects for car travel and for public transport<br>3. positive effect for public transport if it increases connectivity (link to public transport stations) | 1. utility gain of cycling<br>2. switch car to cycling<br>3. switch public transport to cycling or increase public transport in combination with cycling |
| transportation sector | **32** | **development of electricity-based fuels (alternative fuels)** | “green hydrogen” | new infrastructure demand | long term alternative |
| transportation sector | **33** | **supporting advanced bio-fuels (alternative fuels)** | increase of bio-fuel supply | 1. biofuels are competing for landuse with food-land<br>2. benefit of reusing of existing infrastructure<br>3. potential incentive to cheat | 1. reducing GHG footprint of CEV<br>2. extends lifetime of existing infrastructure<br>3. land-use change food-crops vs energy-crops |

| | | | | | |
|---|---|---|---|---|---|
| transportation sector | 34 | strengthening rail cargo traffic | 1. increased reliability, capacity<br>2. increasing rail_cargo numbers | 1. increase image<br>2. reducing cargo via road/air transport<br>3. GHG emissions | not relevant |
| transportation sector | 35 | modernizing inland waterway transport and utilizing land-based electricity in harbors | increasing efficiency of water transport | 1. increase image<br>2. GHG emissions | not relevant |
| transportation sector | **36** | **increase low-CO2 passenger cars on roads** | 1. tighten emission targets (95g/km) | 1. GHG emissions<br>2. fleet efficiency increase<br>3. shift to non-CO2 emissions<br>4. shadow-registrations to squeeze fleet emissions<br>5. development of EV and HEV/PHEV market | 1. increased new registrations of efficient cars<br>2. increased upgrading of inefficient cars |
| transportation sector | **37** | **expansion of refueling and charging infrastructure** | infrastructure improvement and attractiveness | 1. increased utility of EV drives EV sales<br>2. electricity demand | increased utility and sales of EV |
| transportation sector | 38 | increase low-CO2 trucks on roads | 1. tighten emission targets (95g/km) | 1. GHG emissions<br>2. fleet efficiency increase<br>3. shift to non-CO2 emissions<br>4. shadow-registrations to squeeze fleet emissions<br>5. development of EV and HEV/PHEV market | not relevant |
| transportation sector | **39** | **expansion of refueling, charging and overhead wiring infrastructure** | infrastructure improvement and attractiveness | 1. increased utility of EV drives EV sales<br>2. electricity demand | increased utility and sales of EV |
| transportation sector | **40** | **automating, connecting, liquifying traffic. enable innovative modes of transport** | 1. increase efficiency of traffic behavior<br>2. less GHG emissions | higher total energy consumption through implementing digital infrastructure | general efficiency gain for all cars |
| transportation sector | **41** | **tax relief program for electric vehicles** | incentive to by EV | 1. electronic waste increase<br>2. special materials demand increase (Li, Si, REM…) | 1. EV sales driver<br>2. GHG emissions reductions<br>3. electronic waste<br>4. special materials demand for manufacturing<br>5. electricity demand increase<br>6. fuel demand decrease |
| industry sector | 42 | investment program: energy efficiency and process heat from renewable energy in the economy | energy efficiency gains | none | not relevant |

| | | | | | |
|---|---|---|---|---|---|
| industry sector | 43 | competitive tender for energy efficiency: subsidy program | ? | ? | not relevant |
| industry sector | 44 | resource efficiency and substitution | 1. increased recycling<br>2. energy efficiency | GHG emissions | not relevant |
| industry sector | 45 | new construction techniques and materials for low-emission industry | 1. increased recycling<br>2. energy efficiency | GHG emissions | not relevant |
| industry sector | 46 | accelerated implementation of measures from the energy-audit and energy management systems (EMS) and effective updating of accepted pairing | ? | ? | not relevant |
| industry sector | 47 | EU-ecological-design-guide-line: expansion of minimum requirements | none | none | not relevant |
| industry sector | 48 | EU-ETS innovation fund: upgrading the NER300-program | ? | ? | not relevant |
| industry sector | 49 | national decarbonization program | energy efficiency gains | GHG emissions | not relevant |
| industry sector | 50 | program for CO2-avoidance and utilization in primary industries | energy efficiency gains | GHG emissions, emissions of other chemicals | not relevant |
| industry sector | 51 | automobile industry: industrial manufacturing of mobile and stationary energy storage (battery cells manufacturing) | energy efficiency gains | 1. electronic (hazardous) waste increase<br>2. special materials demand increase (Li, Si, REM...) | not relevant |
| agriculture sector | 52 | reducing nitrogen surpluses, ammonia emissions, and laughing gas emissions as well as increasing nitrogen efficiency | left out | none | not relevant |
| agriculture sector | 53 | strengthening the fermentation of economic fertalizers of animal origin and agricultural recycling material | ? | ? | not relevant |
| agriculture sector | 54 | expansion of ecological agriculture | left out | none | not relevant |
| agriculture sector | 55 | reducing greenhouse gas emissions from animal husbandry | left out | none | not relevant |
| agriculture sector | 56 | energy efficiency in agriculture | left out | none | not relevant |

| | | | | | |
|---|---|---|---|---|---|
| other measures | 57 | subsidy program for expanding landfill ventilation and optimizing gas abstraction | ? | ? | not relevant |
| land-use land-use change and forestry sector | 58 | maintenance and building up of topsoil of arable farm land | left out | none | not relevant |
| land-use land-use change and forestry sector | 59 | maintaining permanent grassland | left out | none | not relevant |
| land-use land-use change and forestry sector | 60 | protecting peaty soil including reducing the use of peat in substrates | left out | none | not relevant |
| land-use land-use change and forestry sector | 61 | maintainance and sustainable management of forests and lumber utilization | left out | none | not relevant |
| overarching measures | 62 | climate neutral federal administration until 2030 | ? | ? | policy target |
| overarching measures | 63 | sustainable finance | ? | ? | not relevant |
| overarching measures | 64 | research and innovation | ? | ? | not relevant |
| overarching measures | 65 | climate protection and society | ? | ? | not relevant |

source: Bundesministerium für Umwelt Naturschutz und nukleare Sicherheit (BMU). (2019d). Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050.

# Appendix B System Boundary Definition

The system boundary definition is further outlined in more detail with regard to individual characteristics.

**Spatial limits**

In order to find a balance between high resolution and high simulation performance, administration districts in Germany were chosen as the smallest geographical elements, the country as a whole as the largest. Administration districts can also be summarized by states as an intermediate level. Other supra- and international relationships, such as the European Union and neighboring countries, are considered as the rest of the world, which is not connected to the model.

**Temporal limits**

The energy transition will stretch over a very long time frame. The government set its immediate targets ten years ahead (CPP2030), formulated the CPP2050 for the next 30 years, and important dates in the overarching issue of climate change frequently include the year 2100 and beyond. Similarly, this research considers a short term time frame referring to the next 10 years, a medium time horizon to cover the next 30 years and the long term to go until 2100. Simultaneously, processes are happening slowly and thus the smallest time unit to consider is one year.

**Energy limits**

Dealing with an aggregated view, relevant characteristic values are in "kW" or "kWh", often in relation to square meters and year, and aggregated consumption values in "TW" or "TWh", often as a yearly consumption value "TWh/a". For simplicity reasons, whereas installed capacity (often in "MW" or "GW") is the typical unit of comparing power plants but which says little about the final energy output, this model deals in annual energy output units (TWh/a) based on average load factors.

**Social limits**

Considering the scope of the research, important model components are aggregated forms of households, building population, the labor force in specific sectors, the different transportation sectors and specifically the population of cars in Germany, as well as the electricity production sector. Every aspect is part of the model where these parts logically connect due to their direct or indirect relationship to the energy transition and climate change. Energy consumption by non household and transportation sectors is part of the rest of world with the exception of electricity consumption. However, electricity consumption from non-focal sectors will be kept constant throughout the model. Additionally, anything related to cargo transport lies outside the scope of this research and is therefore part of the rest of the world.

Individual societal behavior is not in the scope of this research in contrast to aggregated behavior trends that may be affected by relative changes between incentive factors such as dedicated budget, costs, utility and availability. Since the workings of the choice mechanism of citizens is a black box, behavioral changes are derived from the relative changes in incentive factors.

**Technological limits**

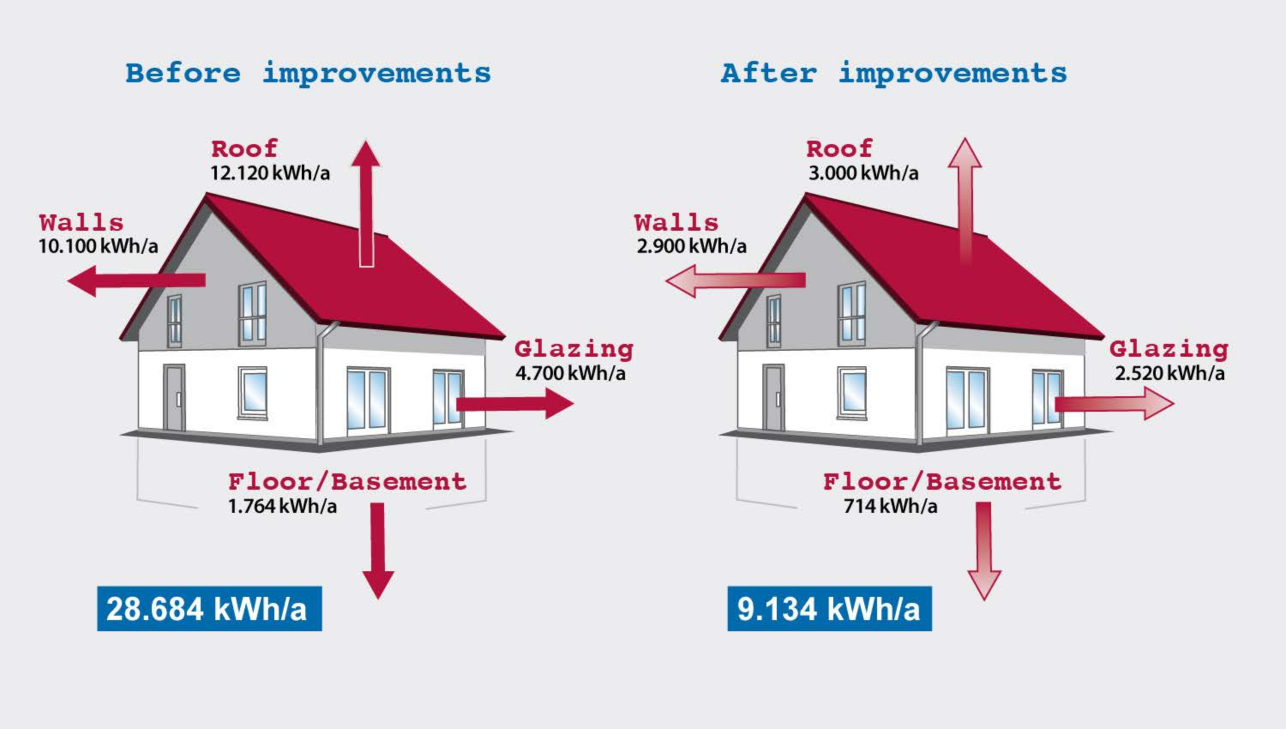
The energy transition is all about consumption, production and preservation of energy and climate change is driven by GHG emissions. However, our society today and the society of the future are and will rely on a multitude of technologies that reflect the unique distribution of resources, geographical conditions, cultural differences, and other attributes. Locations, regions, provinces and states all have their own governmental institutions and rules, not to mention citizens' individual preferences. Consequently there is a variety of technologies in use to fulfil very similar tasks with regard to household heating, building energy efficiency, electricity production and mobility services. Each of these areas comprise their own set of technologies with different energy properties and GHG emissions. The technologies by themselves are considered blackboxes in this modelling project, their workings are not important, only their input and output streams of energy, emissions, and related resources. Consequently, the different technology types are made explicit in the model by accounting for their different energy and emissions behavior. In the case of housing insulation, this translates to considering the heating energy efficiency improvement effect per each area of living space transformed. This effect is attributed by an estimated value rather than the specific U-value (heat transfer coefficient) and its functioning.

Similarly, individual institutions and other actors or legal bodies are not represented in the model structure, only their possible actions are implemented by means of external policy levers or uncertainties that limit, boost or hinder the model behavior.

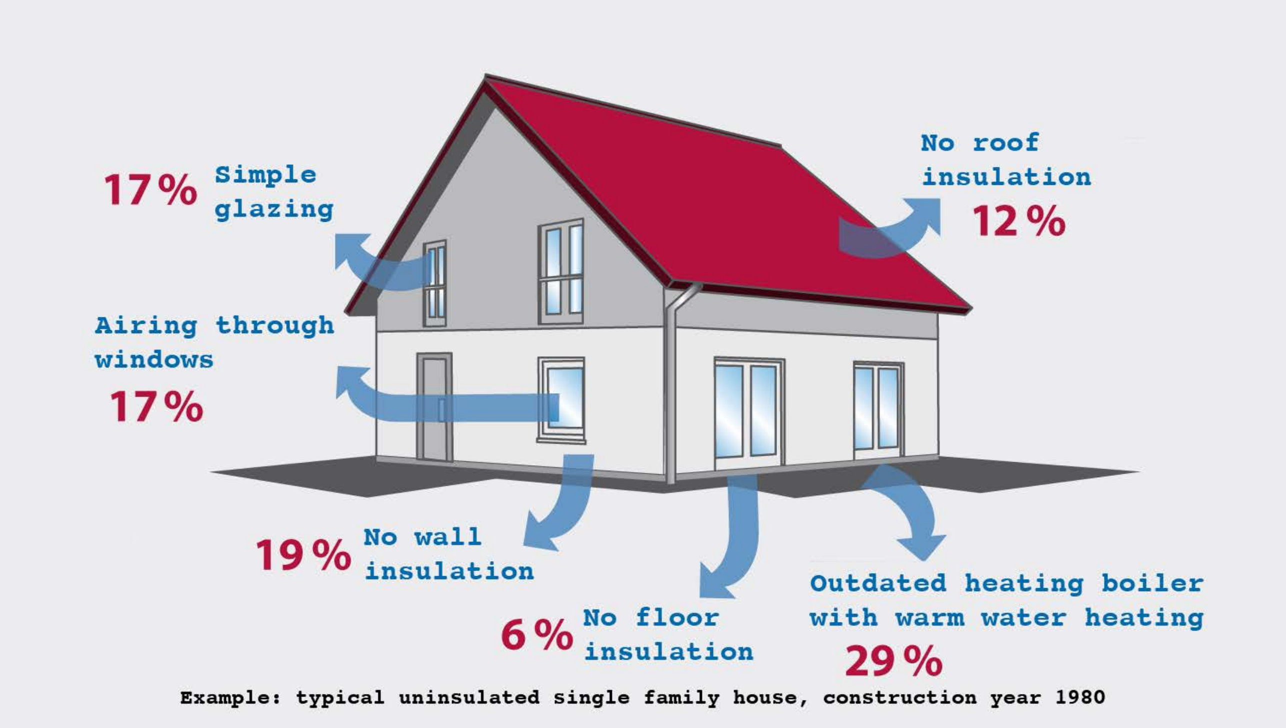
# Appendix C - The Housing Sector

This section contains more detailed thoughts and information on the housing sector.

## C.1 - Energy loss potential of building components



source: www.bdew.de/service/daten-und-grafiken/infografiken-gebaeudetechnik/



source: www.bdew.de/service/daten-und-grafiken/infografiken-gebaeudetechnik/

# C.2 Energy efficiency potential from upgrades

Based on the initial energy consumption characteristic of living space per construction year (**Table 1 - Heating energy demand characteristic value by building size and construction year)**, the energy efficiency gain potential per building component is derived by the following logic. Each construction year is assigned a general potential of being improved by upgrading (**table X constr age upgrd potential**), which is multiplied with the individual improvement potential of the components (**table X component upgrd potential**) and finally multiplied with the initial energy demand characteristic (**Table 1 - Heating energy demand characteristic value by building size and construction year)**.

### Table C.2.1 - Floor upgrade energy consumption improvement

| **Construction year** | **1 dwelling** in kWh/(m2*a) | **2 dwellings** in kWh/(m2*a) | **3-6 dwellings** in kWh/(m2*a) | **7-12 dwellings** in kWh/(m2*a) | **13plus dwellings** in kWh/(m2*a) |
|---|---|---|---|---|---|
| **pre 1919** | 3 | 3 | 3 | 3 | 2 |
| **1919-1948** | 5 | 4 | 4 | 4 | 3 |
| **1949-1978** | 5 | 5 | 4 | 4 | 4 |
| **1979-1990** | 3 | 3 | 3 | 4 | 3 |
| **1991-2000** | 3 | 2 | 3 | 2 | 2 |
| **2001-2008** | 2 | 2 | 2 | 2 | 2 |
| **2009-2020** | 1 | 1 | 1 | 2 | 2 |
| **2021 and later** | 0 | 0 | 0 | 0 | 0 |

### Table C.2.2 - Glazing upgrade energy consumption improvement

| **Construction year** | **1 dwelling** in kWh/(m2*a) | **2 dwellings** in kWh/(m2*a) | **3-6 dwellings** in kWh/(m2*a) | **7-12 dwellings** in kWh/(m2*a) | **13plus dwellings** in kWh/(m2*a) |
|---|---|---|---|---|---|
| **pre 1919** | 10 | 9 | 8 | 8 | 7 |
| **1919-1948** | 13 | 12 | 11 | 10 | 9 |
| **1949-1978** | 12 | 12 | 11 | 11 | 10 |
| **1979-1990** | 8 | 8 | 8 | 9 | 7 |
| **1991-2000** | 7 | 6 | 7 | 6 | 6 |
| **2001-2008** | 4 | 4 | 4 | 4 | 4 |
| **2009-2020** | 4 | 4 | 4 | 5 | 5 |
| **2021 and later** | 0 | 0 | 0 | 0 | 0 |

### Table C.2.3 - Roof upgrade energy consumption improvement

| **Construction year** | **1 dwelling** in kWh/(m2*a) | **2 dwellings** in kWh/(m2*a) | **3-6 dwellings** in kWh/(m2*a) | **7-12 dwellings** in kWh/(m2*a) | **13plus dwellings** in kWh/(m2*a) |
|---|---|---|---|---|---|
| **pre 1919** | 23 | 22 | 20 | 19 | 17 |
| **1919-1948** | 27 | 25 | 23 | 20 | 19 |
| **1949-1978** | 26 | 25 | 22 | 22 | 20 |
| **1979-1990** | 14 | 13 | 13 | 15 | 11 |
| **1991-2000** | 10 | 10 | 10 | 9 | 9 |
| **2001-2008** | 6 | 6 | 6 | 6 | 6 |
| **2009-2020** | 4 | 5 | 5 | 6 | 6 |
| **2021 and later** | 0 | 0 | 0 | 0 | 0 |

**Table C.2.4 - Wall upgrade energy consumption improvement**

| **Construction year** | **1 dwelling** in kWh/(m2*a) | **2 dwellings** in kWh/(m2*a) | **3-6 dwellings** in kWh/(m2*a) | **7-12 dwellings** in kWh/(m2*a) | **13plus dwellings** in kWh/(m2*a) |
|---|---|---|---|---|---|
| **pre 1919** | 20 | 19 | 18 | 16 | 14 |
| **1919-1948** | 23 | 21 | 20 | 18 | 16 |
| **1949-1978** | 23 | 22 | 20 | 19 | 18 |
| **1979-1990** | 13 | 12 | 12 | 14 | 10 |
| **1991-2000** | 10 | 9 | 10 | 9 | 8 |
| **2001-2008** | 6 | 5 | 6 | 6 | 6 |
| **2009-2020** | 4 | 4 | 4 | 5 | 6 |
| **2021 and later** | 0 | 0 | 0 | 0 | 0 |

**Table C.2.5 Heating system upgrade energy consumption improvement**

| **Construction year** | **1 dwelling** in kWh/(m2*a) | **2 dwellings** in kWh/(m2*a) | **3-6 dwellings** in kWh/(m2*a) | **7-12 dwellings** in kWh/(m2*a) | **13plus dwellings** in kWh/(m2*a) |
|---|---|---|---|---|---|
| **pre 1919** | 24 | 23 | 21 | 19 | 17 |
| **1919-1948** | 29 | 27 | 24 | 22 | 20 |
| **1949-1978** | 30 | 28 | 25 | 25 | 23 |
| **1979-1990** | 17 | 16 | 16 | 19 | 14 |
| **1991-2000** | 13 | 13 | 13 | 12 | 11 |
| **2001-2008** | 8 | 8 | 8 | 8 | 8 |
| **2009-2020** | 6 | 7 | 7 | 8 | 9 |
| **2021 and later** | 0 | 0 | 0 | 0 | 0 |

# C.3 Household budget

### Household net income

Table C.3.1 illustrates the initially assumed average monthly net income per household and income group. For the group with income below EUR 900 an average of EUR 700 was assumed, considering this group includes students, minimum wage workers, trainees and career entrants. The income groups distinguished by an upper and lower bound were assigned the respective mean value. Finally, great uncertainty lies in the average income of households earning more than EUR 10.000 per month because there is no real upper limit as this is the realm of so-called "extremistan" as Taleb (2007) described it in "The Black Swan". First it is assumed that a plausible mean could lie around 10% of the total benefits of the best earning citizens in Germany. According to Wikipedia[1] about 17.400 people with an income over EUR 1 million were counted in 2013. In an SWR Aktuell article Thiele (2020) reports highest earnings by managers from the Volkswagen group with an average of EUR 5,7 million per year and of close to EUR 10 million per year for the Volkswagen AG CEO, which is supported by the company's annual report (Volkswagen AG, 2020). Thus initially an average annual income of EUR 1 million was assigned to the last

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[1] de.wikipedia.org/wiki/Einkommensmillion%C3%A4r

income group. However, a quick validation test suggested significant adjustment needs as illustrated in **Table C.3.1**.

**Table C.3.1 - Validation test of initial income assumption**

| Income groups | Initial assumed average monthly net income per household | Initial assumed average annual net income per household | Number of households per group | Cumulated annual income per group in EUR |
|---|---|---|---|---|
| **below EUR 900** | EUR 700 | EUR 8.400 | 2.940.000 | 24.696.000.000 |
| **EUR 900-1500** | EUR 1200 | EUR 14.400 | 7.117.000 | 102.484.800.000 |
| **EUR 1500-2000** | EUR 1750 | EUR 21.000 | 6.367.000 | 133.707.000.000 |
| **EUR 2000-3200** | EUR 2600 | EUR 31.200 | 10.835.000 | 338.052.000.000 |
| **EUR 3200-4500** | EUR 3850 | EUR 46.200 | 6.777.000 | 313.097.400.000 |
| **EUR 4500-6000** | EUR 5250 | EUR 63.000 | 3.407.000 | 214.641.000.000 |
| **EUR 6000-10000** | EUR 8000 | EUR 96.000 | 2.587.000 | 248.352.000.000 |
| **EUR 10000 plus** | EUR 83000 | EUR 1.000.000 | 515.000 | 515.000.000.000 |
| **Sum** | - | - | **40.545.000** | **1.890.030.200.000** |
| **Residual annual per capita income** | | | | **EUR 23.625** |

The test was done by multiplying the average income values by the number of households per group and dividing the total by 80 million German citizens in order to obtain the average annual per capita income of Germany. The residual annual per capita income for Germany amounts to EUR 23.625, which is about EUR 20.000 short of the actual amount of about EUR 43.000 in 2018[2].

Subsequently the average income for last income group was raised four times to EUR 332.000 per month so that an approximately realistic per capita income of EUR 42.835 was achieved. The final income configuration is outlined in **Table C.3.2** below. Of course also different mean values for the other income groups could have been chosen, focusing on adjusting the highest income group was perceived to involve less uncertainty, however.

**Table C.3.2 - Final income configuration**

| Income groups | Initial assumed average monthly net income per household | Initial assumed average annual net income per household | Number of households per group | Cumulated annual income per group in EUR |
|---|---|---|---|---|
| **below EUR 900** | EUR 700 | EUR 8.400 | 2.940.000 | 24.696.000.000 |
| **EUR 900-1500** | EUR 1200 | EUR 14.400 | 7.117.000 | 102.484.800.000 |
| **EUR 1500-2000** | EUR 1750 | EUR 21.000 | 6.367.000 | 133.707.000.000 |
| **EUR 2000-3200** | EUR 2600 | EUR 31.200 | 10.835.000 | 338.052.000.000 |
| **EUR 3200-4500** | EUR 3850 | EUR 46.200 | 6.777.000 | 313.097.400.000 |
| **EUR 4500-6000** | EUR 5250 | EUR 63.000 | 3.407.000 | 214.641.000.000 |
| **EUR 6000-10000** | EUR 8000 | EUR 96.000 | 2.587.000 | 248.352.000.000 |
| **EUR 10000 plus** | EUR 332000 | EUR 3.984.000 | 515.000 | 2.051.760.000.000 |
| **Sum** | - | - | **40.545.000** | **3.426.790.200.000** |
| **Residual annual per capita income** | | | | **42.835** |

### Household available income

Depending on the household's income level, the share of net income a household can spend on improvements varies greatly. Due to lack of data, it is assumed that households earning up to EUR 1.500

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[2] de.wikipedia.org/wiki/Deutschland

per month need all they have to cover their basic needs, such as rent, food, clothing and other necessities. The income group EUR 1.500-2.000 is assumed to be earning just enough to be able to spend 5% of income on non-essential things. The **Table C.3.3** shows the assumptions for each income group.

**Table C.3.3 - household share of net income available for non essential spending**

| Income groups | Assumed share of net income available for non essential spending |
|---|---|
| **below EUR 900** | 0 % |
| **EUR 900-1500** | 0 % |
| **EUR 1500-2000** | 5 % |
| **EUR 2000-3200** | 10 % |
| **EUR 3200-4500** | 25 % |
| **EUR 4500-6000** | 50 % |
| **EUR 6000-10000** | 70 % |
| **EUR 10000 plus** | 90 % |

Finally, multiplying the total available income per income group with the assumed share of income that each group can spare for investments underlines the "extremistanian" nature of income (Taleb, 2007). More than 82% of the total available budget for (sustainability) improvements is supposedly earned by the very rich. This strongly calls for policy measures that have a redistributive effect.

**Table C.3.4 - Residual budget available for improvement investments**

| Income groups | Residual budget available for improvement investments per income group in EUR | Fraction of cumulated budget |
|---|---|---|
| **below EUR 900** | 0 | 0,00 % |
| **EUR 900-1500** | 0 | 0,00 % |
| **EUR 1500-2000** | 6.685.350.000 | 0,30 % |
| **EUR 2000-3200** | 33.805.200.000 | 1,50 % |
| **EUR 3200-4500** | 78.274.350.000 | 3,48 % |
| **EUR 4500-6000** | 107.320.500.000 | 4,78 % |
| **EUR 6000-10000** | 173.846.400.000 | 7,74 % |
| **EUR 10000 plus** | 1.846.584.000.000 | 82,20 % |
| **Sum** | 2.246.515.800.000 | 100,00 % |

# C.5 Household improvements workforce

Obtained from Destatis data, the workforce of construction and finishing trades in Germany is displayed in the following the **Table 1: Workforce overview: Main construction trades** and **Table 1: Workforce overview: Finishing trades**. Next to the number of workers per profession it is also highlighted which professions are assumed to be able to carry out specific improvement works, which indicates their relevance to this research.

Table 1: Workforce overview: Main construction trades

| Professions | Workforce | Improvements expertise |
|---|---|---|
| Masons and concrete workers | 372028 | - |
| Carpenters | 89038 | Insulation work |
| Roofers | 94631 | Insulation work |

| | | |
|---|---:|---|
| Road builders | 123020 | – |
| Heat cold and sound insulation workers | 13105 | Insulation work |
| Well builders | 4953 | – |
| Scafforders | 27766 | – |
| Concrete block and terrazzo builders | 3388 | – |

source: destatis-53111

Table 1: Workforce overview: Finishing trades

| **Professions** | **Workforce** | **Improvements expertise** |
|---|---:|---|
| Stove and air heating builders | 7722 | – |
| Plasterers | 30886 | – |
| Painters and varnishers | 207575 | – |
| Tinsmiths | 23999 | – |
| Plumbers and heating engineers | 327340 | Heating system installations, Solar thermic installations |
| Electrical engineers | 445803 | Solar PV installations |
| Joiners | 200352 | – |
| Glaziers | 23390 | – |
| Floor tilers | 98892 | – |
| Composition floor layers | 17467 | – |
| Parquet layers | 15175 | – |
| Roller blinds and sun shutter technicians | 17477 | – |
| Interior decorators | 49838 | – |

source: destatis-53111

# Appendix D - The Personal Transportation Sector

## Data cleaning and preparation

The KBA collects its data on community level and includes all intermediate aggregation levels so that one and the same table reveals highly aggregated and disaggregated data at the same time. For this research only data on administration district level is extracted from this dataset. Additionally, the naming convention of the KBA dataset and the master dataset, derived from the census 2011 data, is not exactly the same and need to be harmonized. This includes accounting for several mergers of administration districts since 2011 that need to be reverse engineered to match the data accurately. Finally, the KBA data on the car stock of 2019 and the new car registrations in 2019 needs to match the structure of the master dataset. In both cases python programming is used to handle the large datasets efficiently. Reverse engineering the merged communities and administration districts is the only case that required manual data input to make the data fit.

The reorganization of regional governments in Germany is summarized on Wikipedia[3]. The relevant changes after 2011 affected the administration districts in the states of Mecklenburg-Vorpommern, Niedersachsen, and Rheinland-Pfalz.

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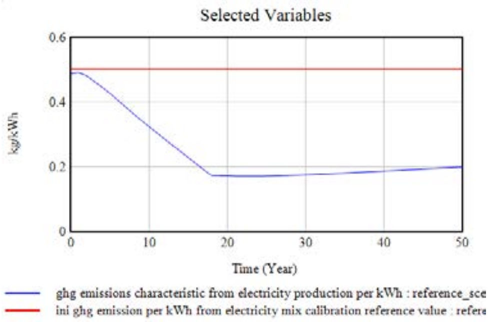
[3] https://de.wikipedia.org/wiki/Kreisreformen_in_Deutschland_nach_1990

# Appendix E - Model-based decision-making

## E.1 Verification and Validation indicators

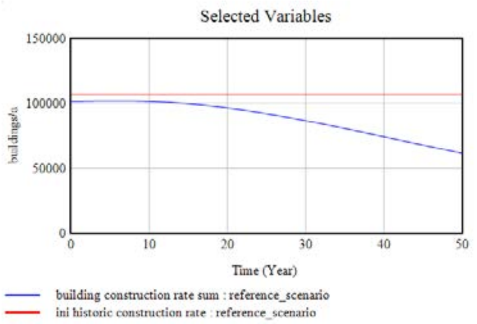
### E.1.1 Energy

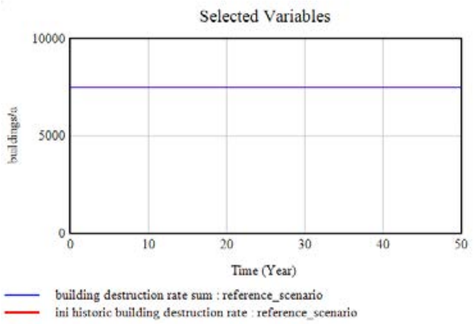
The initial ghg emissions characteristic from electricity production per kWh (blue) values come very close to the data reference point (red). This is an important indicator because it will be multiplied with the final electricity consumption and could cause severe misinterpretation:



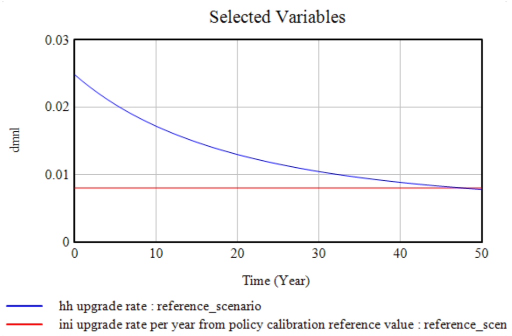
### E.1.2 Housing

Whereas the building construction rate (blue) diverges over time from the reference (red), the modelled building destruction rate has exactly the same behavior as the reference data:

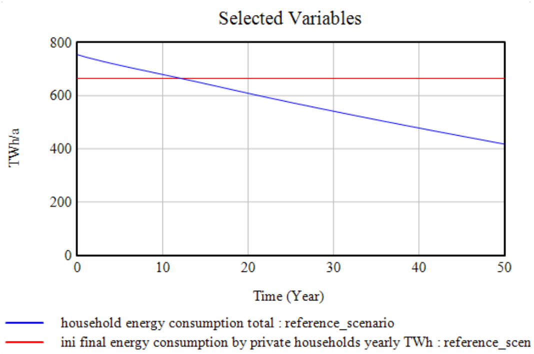




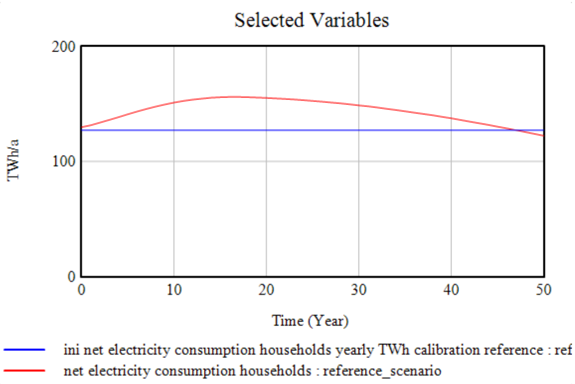
Housing upgrade rate (blue) starts of slightly above the historic reference (red):



The total energy consumption of households (blue) starts in the area of the reference data (red):

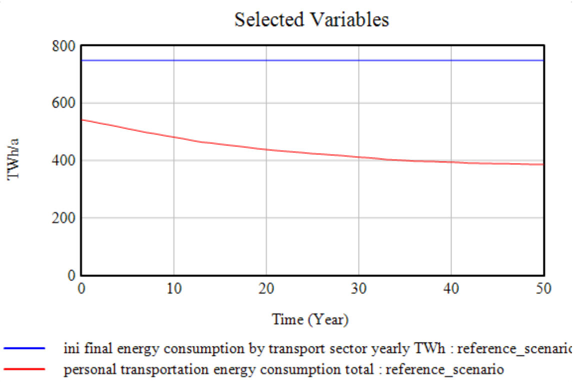


The net energy consumption of households (red) starts off very close to the historic data point (blue), follows the expected energy trend and then meets the modelled system effect of other factors and declines:



### E.1.3 Transportation

The total energy consumption from personal transportation (red) does not include international trips and water way transportation. Especially international air travel is very energy intensive and causes the reference data (blue) to signal a slight mismatch to the model behavior:



## E.2 XLRM Framework

Table E.1 - XRLM Uncertainties

| **Block** | **Uncertainties (UNC)** | **UNC value range** | **UNC initial value** | **Type of uncertainty** | **Reasoning** |
|---|---|---|---|---|---|
| **ENERGY SECTOR** | | | | | |
| **Electricity production** | UNC intrinsic repowering share | -0,22 - 0,78 | 0 | deep | Repowering is almost as expensive as new construction, small synergy effects |
| **Electricity production** | UNC effective wind solar implementation rate | 0 - 100 | 90 | stochastic removed from eval. | Construction permissions have been granted, high historic fallout rates from protests and lawsuits, new legislation reduces risks of lawsuits (RP-Online, 2020) |
| **Electricity production** | UNC coal and oil transfer to gas boom factor | 0 - 0,5 | 0 | deep | Lost capacity in coal, oil and nuclear could be replaced quickly by gas turbines, increased gas supply from Nord Stream 2 |
| **Electricity price** | UNC base gain electricity price | -15 - 15 | 7,5 | deep | historic energy price trend indicates constantly rising prices, potentially higher grid stability costs from energy transition |
| **Fossil fuel prices** | UNC transportation fossil fuel price gain | -15 - 15 | 0 | deep | historic energy price trend indicates constantly rising prices, potentially higher grid stability costs from energy transition |
| **GHG emissions prices** | UNC co2equ price development | -10 - 10 | 0 | deep | currently price increase relies on governmental intervention, functioning of future price setting mechanism is uncertain |
| | | | | | |
| **HOUSING SECTOR** | | | | | |
| **Household electricity use** | UNC expected electricity consumption increase | 0 - 20 | 12 | stochastic | expected increase (Agora Energiewende & Wattseight, 2020; Bundesverband Erneuerbare Energie, 2020; Bundesnetzagentur, 2020) |
| **Household budget** | UNC base fraction of household income dedicated to improvement investments | 0,005 - 0,05 | 0,025 | deep | depending on economic development and citizens spending priorities in the future |
| **Household budget** | UNC housig upgrades over car preference assumtion | 0 - 1 | 0,5 | deep | depending on the relative utility change between cars and housing improvements |
| **Improvements** | UNC global handicap improvement working hours | 0 - 1 | 0,2 | deep | uncertainty of allocation mechanism of work hours for housing improvements and future development |
| **Improvements** | UNC global handicap improvement funding | 0 - 1 | 0,2 | deep | uncertainty of allocation mechanism of funding for housing improvements and future development |
| **Household heating system upgrades** | UNC factor on gas heating | 0 - 10 | 1 | deep | coal/oil heating households could switch to gas boilers or alternative technologies. preferences are uncertain |
| | | | | | |
| **PERSONAL TRANSPORTATION SECTOR** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **New car registrations technology preference** | UNC car reductions on avg base sales price per type | 0,0005 - 0,01 | 0,005 | stochastic removed from eval. | infant technology becomes cheaper over time, starting with more upper-class models the future adds more smaller/cheaper models dropping the average base sales price for EV |
| **New car registrations technology preference** | UNC historic base gain yearly mileage avg | -100 - 100 | -60 | stochastic removed from eval. | historic data shows slight decrease in mileage/year |
| **New car registrations technology preference** | UNC new car pref objection against new technologies | 0 - 50 | 20 | deep | car technology preference influenced by non-monetary and personal utility factors |
| **Mode of transportation preferences** | UNC relative utility of public transportation and railway change | -50 - 50 | 0 | deep | public transportation and railway preference influenced by non-monetary and personal utility factors |
| **New car registrations** | UNC relative change in transport mode effect on car owning factor | 0,1 - 0,666 | 0,333 | deep | concers the potential causal link between demand for transportation services and demand for cars |
| **Energy consumption from personal transportation** | UNC EV base share capacity charged at home | 0 - 1 | 0,8 | stochastic removed from eval. | if drivers charge at home or not has no impact on the model outcomes |
| **Energy consumption from personal transportation** | UNC alternative transprotation electrification rate handicap | 0 - 1 | 0 | deep | the optimism of public transportation providers are to upgrade to electric busses could be short lived or could have a domino-effect and bring swift change |

## Table E.2 - XLRM Levers

| **Block** | **Levers** | **Levers value range** | **Levers BAU value** |
|---|---|---|---|
| **ENERGY SECTOR** | | | |
| **Electricity production** | lever policy target total repowering share | 0 - 1 | 0 |
| **Electricity production** | lever policy pref new electricity technology gas | 0 - 0,4 | 0,2 |
| **Electricity production** | lever policy pref new electricity technology solar | 0 - 0,4 | 0,3 |
| **Electricity production** | lever policy pref new electricity technology wind | 0 - 0,4 | 0,3 |
| **Electricity production** | lever policy pref new electricity technology geothermal | 0 - 0,4 | 0,01 |
| **Electricity price** | lever gov incentive on electricity price | 0 - 0,2 | 0 |
| **Fossil fuel prices** | lever policy transport fuel surcharges | 0 - 0,5 | 0 |
| **GHG emissions prices** | lever policy szenario maximum limit following 2030 | 0 - 1000 | 100 |
| | | | |
| **HOUSING SECTOR** | | | |
| **Household electricity use** | lever electricity use policies | -1000 - 1000 | 0 |
| **Household budget** | lever policy on willingness to invest in upgrades addons car upgrds | 0-0,05 | 0,0005 |
| **Improvements workforce** | lever policy training of insulation installers | 0 - 50000 | 0 |
| **Improvements workforce** | lever policy training of heating system installers | 0 - 100000 | 0 |

| | | | |
|---|---|---|---|
| **Improvements workforce** | lever policy training of solar pv installers | 0 - 50000 | 0 |
| **Improvements workforce** | lever policy training of solar thermal installers | 0 - 50000 | 0 |
| | | | |
| **PERSONAL TRANSPORTATION SECTOR** | | | |
| **New car registrations technology preference** | lever gov financial support for PHEV extension | 0 - 25000 | 0 |
| **New car registrations technology preference** | lever gov financial support for BEV extension | 0 - 30000 | 0 |
| **New car registrations technology preference** | lever relative policy incentive EV over CEV | 0 - 1000 | 0 |
| **Personal transportation demand** | lever policy trend effects on personal mobility demand | -150 - 150 | 0 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of cars | 0 - 100 | 0 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of public transportation | 0 - 100 | 0 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of railways | 0 - 100 | 0 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of air travel | 0 - 100 | 0 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of cycling | 0 - 100 | 0 |

Table E.1 - XRLM Outcome indicators

| **Block** | **Outcome indicators** | **optimization target** |
|---|---|---|
| **ENERGY SECTOR** | GHG emissions from selected sectors combined | minimize |
| **HOUSING SECTOR** | Net electricity consumption households | maximize |
| **HOUSING SECTOR** | Final disposable yearly income for improvement investments | minimize |
| **PERSONAL TRANSPORTATION SECTOR** | Yearly pkm transportation demand total | maximize |

## E.3 - Experiment Design

The experiments are design assigns different sets of values to the levers, which are then run against the uncertainty ranges in a sensitivity analysis. Experiments 1 and 2 are defined in the table below.

## Table E.3 - Experiments

| **Block** | **Levers** | **Levers value range** | **Experiment 1 (BAU)** | **Experiment 2** |
|---|---|---|---|---|
| **ENERGY SECTOR** | | | | |
| **Electricity production** | lever policy target total repowering share | 0 – 1 | 0 | 0,9 |
| **Electricity production** | lever policy pref new electricity technology gas | 0 – 0,4 | 0,2 | 0 |
| **Electricity production** | lever policy pref new electricity technology solar | 0 – 0,4 | 0,3 | 0,4 |
| **Electricity production** | lever policy pref new electricity technology wind | 0 – 0,4 | 0,3 | 0,4 |
| **Electricity production** | lever policy pref new electricity technology geothermal | 0 – 0,4 | 0,01 | 0,4 |
| **Electricity price** | lever gov incentive on electricity price | 0 – 0,2 | 0 | 0,1 |
| **Fossil fuel prices** | lever policy transport fuel surcharges | 0 – 0,5 | 0 | 1 |
| **GHG emissions prices** | lever policy szenario maximum limit following 2030 | 0 – 1000 | 100 | 1000 |
| | | | | |
| **HOUSING SECTOR** | | | | |
| **Household electricity use** | lever electricity use policies | -1000 – 1000 | 0 | 0 |
| **Household budget** | lever policy on willingness to invest in upgrades addons car upgrds | 0-0,05 | 0,0005 | 0,001 |
| **Improvements workforce** | lever policy training of insulation installers | 0 – 50000 | 0 | 50000 |
| **Improvements workforce** | lever policy training of heating system installers | 0 – 100000 | 0 | 100000 |
| **Improvements workforce** | lever policy training of solar pv installers | 0 – 50000 | 0 | 50000 |
| **Improvements workforce** | lever policy training of solar thermal installers | 0 – 50000 | 0 | 50000 |
| | | | | |
| **PERSONAL TRANSPORTATION SECTOR** | | | | |
| **New car registrations technology preference** | lever gov financial support for PHEV extension | 0 – 25000 | 0 | 10000 |
| **New car registrations technology preference** | lever gov financial support for BEV extension | 0 – 30000 | 0 | 15000 |
| **New car registrations technology preference** | lever relative policy incentive EV over CEV | 0 – 1000 | 0 | 50 |
| **Personal transportation demand** | lever policy trend effects on personal mobility demand | -150 – 150 | 0 | -50 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of cars | 0 – 100 | 0 | 0 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of public transportation | 0 – 100 | 0 | 20 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of railways | 0 – 100 | 0 | 20 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of air travel | 0 – 100 | 0 | 0 |
| **Mode of transportation preferences** | lever gov policy increasing the utility of cycling | 0 – 100 | 0 | 0 |

# Appendix F - Correspondence

The attached copies of correspondence show inquiries about data and data sources on specific datasets that could have benefited the data quality underlying the model. The correspondence includes:

Table F - Correspondence overview

| # | Correspodent | Inquiry summary | Response summary |
|---|---|---|---|
| 1 | **Energie Effizienz Experten (www.energie-effizienz-experten.de)** | data on household energy consumption on level of administration districts | referral to Destatis |
| 2 | **Destatis (www.destatis.de)** | data on administration district level on: building stock by construction year, energy source, household size, building type | various links to data sets: regionalstatistik, micro census 2018 data, and census 2011 data |
| 3 | **Destatis (www.destatis.de)** | data linking different aspects: 1. living space/building type, energy label,<br>2. living space/building type, renovation work with insulation installations,<br>3. living space/building type, energy consumption by source,<br>4. buildings with renewable energy installations by number,<br>5. buildings with renewable energy installations by installed capacity,<br>6. by households produced energy behind the meter | Destatis does not collect these data points, estimates are in micro census 2018. Of further interest could be data from: AG Energiebilanzen (www.ag-energiebilanzen.de), CO2online (www.co2online.de) |
| 4 | **CO2-online (www.co2online.de)** | data points linking aspects of the building stock at high resolution: living space, energy consumption, energy sources, renewable energy installations | referral to associated web-service: www.wohngebaeude.info |
| 5 | **Kraftfahrt-Bundesamt (www.kba.de)** | data on charging capacity of battery electric vehicles and plug-in hybrid electric vehicles | not available |

**From:** **Energieeffizienz-Expertenliste** info@energie-effizienz-experten.de
**Subject:** RE: WG: Energieverbrauch Haushalte
**Date:** 04. February 2020 at 11:24
**To:** i.schonwandt@stud.uis.no

Sehr geehrter Herr Schönwandt,

vielen Dank für Ihre Nachricht.

Allerdings sind wir nicht die richtige Anlaufstelle. Mein persönlicher Vorschlag ist, dass Sie direkt beim Statistischen Bundesamt (Destatis) nachfragen.

Bei Fragen sind wir gerne für Sie da.

Mit freundlichen Grüßen
Ihr Energieeffizienz-Experten-Team
i. A. Carolin Müller

************************************************************
Deutsche Energie-Agentur GmbH (dena)
Energieeffizienz-Expertenliste für Förderprogramme des Bundes

Chausseestr. 128 a
10115 Berlin
Tel: +49 (0)30 66 777 - 222
Fax: +49 (0)30 66 777 - 799
info@energie-effizienz-experten.de
www.energie-effizienz-experten.de
www.dena.de

------------------------------------------------------------
Twitter: twitter.com/dena_news
------------------------------------------------------------

Vertretungsberechtigte Geschäftsführung: Andreas Kuhlmann, Kristina Haverkamp
Aufsichtsratsvorsitzender: Thomas Bareiß
Registergericht: Amtsgericht Charlottenburg
Registernummer: HRB 78 448

-----------------------------------------------
Von: "Susever, Soley" (susever@dena.de)
Gesendet: 03.02.2020 08:24
An: 'Energieeffizienz-Expertenliste' (info@energie-effizienz-experten.de)
Cc: info (info@dena.de)
Betreff: WG: Energieverbrauch Haushalte
----------------------------------------------- -----Ursprüngliche Nachricht----- Von: Ingo Schönwandt [mailto:i.schonwandt@stud.uis.no] Gesendet: Freitag, 31. Januar 2020 18:20 An: info Betreff: Energieverbrauch Haushalte Sehr geehrte Damen und Herren, wo findet man Daten zum Energieverbrauch von Haushalten nach Energieträger auf Kreis- oder Gemeindeebene? Genesis Online stellt keine Daten mit Bezug auf Energie zur Verfügung, sind Sie dafür die richtige Anlaufstelle? Mit freundlichen Grüßen, Ingo Schönwandt

**From:** **Ingo Schönwandt** i.schonwandt@stud.uis.no
**Subject:** Re: Verschiedene Angaben auf regionaler Ebene, Statistisches Bundesamt, GZ 453502 / 648535
**Date:** 24. February 2020 at 17:06
**To:** info@destatis.de

Sehr geehrte Frau Haider,

vielen Dank für Ihre Unterstützung! Besonders Ihr letzter Link zur Seite vom Zensus2011 war sehr hilfreich, wenn auch die Daten extrem alt sind.
Die Daten vom Mikrozensus 2018 helfen aufgrund der sehr groben Auflösung da nur bedingt weiter. Eine Hochrechnung auf kleinere geografische Einheiten gibt es nicht, sofern ich Sie richtig verstehe?

Zudem fehlen mir wichtige Anhaltspunkte, die den Gebäudebestand mit dem Energieverbrauch verbinden, wie:

1. Gebäudetyp/Wohnungsfläche <-> Energie-Label je Gebäude (gem. europäischer Energy Performance of Buildings Directive (EU/2018/844))
2. Gebäudetyp/Wohnungsfläche <-> Nachträgliche Isolationsarbeiten (Fenster, Außenwand, Dachboden, Kellerdecke)
3. Gebäudetyp/Wohnungsfläche <-> Energieverbrauch je Energiequelle in kWh/m2
4. Gebäude mit erneuerbaren Energieanlagen ( Solar PV, Solarthermie, Geothermie, Wärmepumpe, Wind ) in Anzahl ~
5. Gebäude mit erneuerbaren Energieanlagen ( Solar PV, Solarthermie, Geothermie, Wärmepumpe, Wind ) in kWpeak
6. Produzierte erneuerbare Energie hinterm Zähler in kWh

(Gebäudetyp = Einfamilien-, Reihen-, mehrstöckiges Mehrfamilienhaus, Doppenhaushälfte )

Wissen Sie, ob es Daten in dieser Richtung gibt?

Mit freundlichen Grüßen,

Ingo Schönwandt

> On 20. Feb 2020, at 14:23, info@destatis.de wrote:
>
> Statistisches Bundesamt
> Zentraler Auskunftsdienst
>
> Tel. +49 (0) 611 75 2405
> https://www.destatis.de/kontakt
>
> Sehr geehrter Herr Schönwandt,
>
> vielen Dank für Ihre Anfrage vom 4. Februar 2020.
>
> Zunächst möchten wir uns für die verspätete Rückmeldung entschuldigen.
>
> Gerne unterstützen wir Sie bei Ihrer Recherche mit folgenden Informationen:
>
> A) Gebäudebestand auf Landkreisebene
> In der "Regionaldatenbank Deutschland" werden im Rahmen der Fortschreibung des Wohngebäude- u. Wohnungsbestandes Angaben zum Bestand an Wohngebäuden und Wohnungen in Wohn- und Nichtwohngebäuden auf Ebene der Kreise und kreisfreien Städte gemacht:
>
> https://www.regionalstatistik.de/genesis/online/logon
>
> Bitte geben Sie in der Suche den Code 31231 ein und wählen die vierte Tabelle aus. Im Tabellenaufbau können Sie nach Jahren und einzelnen Kreisen und kreisfreien Städten auswählen. Bitte bestätigen Sie Ihre Eingaben mit "übernehmen" und rufen anschließend die ausgewählten Daten mit dem Button "Werteabruf" ab. Die angezeigte Datentabelle können Sie sich u.a. im Excel-Format abspeichern.
>
> B) Baujahr, Energiequelle, Größe von Haushalten und Gebäudetyp/Bauart
> In unserer Publikation "Wohnen in Deutschland - Zusatzprogramm des Mikrozensus 2018" finden Sie Angaben zu Baujahr, Energieart/Beheizung, der Größe von Haushalten und zu Gebäudetypen bis auf Ebene der Regierungsbezirke:
>
> https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Wohnen/_inhalt.html#sprg233558
>
> Unter 'Publikationen'/'Wohnsituation' finden Sie die Veröffentlichung.
>
> Bitte beachten Sie:
> Der Mikrozensus ist eine 1%-Stichprobe der Bevölkerung. Aus Datenschutzgründen (Geheimhaltung) können die Daten jedoch nur bis auf Ebene der sogenannten 'Regionalen Anpassungsschichten' (s. Anlagen) ausgewertet werden.
>
> Des Weiteren finden wir Ihnen die Ergebnisse des Zensus 2011 mit Angaben in tiefer regionaler Gliederung:
> https://ergebnisse.zensus2011.de/#StaticContent:00,,,

> https://www.zensus2011.de/DE/Home/Aktuelles/DemografischeGrunddaten.html?nn=3065474
>
> Bei weiteren Fragen stehen wir Ihnen gern zur Verfügung.
> Bitte nutzen Sie dafür unser Kontaktformular https://www.destatis.de/kontakt/
>
> Mit freundlichen Grüßen
> Im Auftrag
>
> Marie-Louise Haider
>
> ---
>
> Zur Beantwortung Ihrer Anfrage haben wir die von Ihnen mitgeteilten personenbezogenen Daten gespeichert. Die Informationen und Hinweise zum Datenschutz nach Art. 13 der Datenschutzgrundverordnung (DS-GVO) finden Sie unter: https://www.destatis.de/DE/Service/Datenschutz/_inhalt.html.

**From:** **Ingo Schönwandt** i.schonwandt@stud.uis.no
**Subject:** Re: Angaben zum Gebäudebestand mit Energieverbrauch, Statistisches Bundesamt, GZ 453502 / 648535
**Date:** 11. March 2020 at 16:26
**To:** info@destatis.de

Sehr geehrte Frau Haider,

ganz herzlichen Dank für Ihre Nachforschungen! Auf die AG Energiebilanz und CO2Online war ich auch schon gestoßen, ja. CO2Online hat eventuell Schätzwerte zum Thema Isolierungsstand und Energieeffizienz, konnten mir aber auch noch nichts konkretes schicken.

Vor dem Hintergrund des Klimawandels, der uns ja wohl noch einige Jahrzehnte beschäftigen wird, und aus Sicht der Public Governance, wäre es sicherlich interessant die genannten Indikatoren auch im Zensus mit abzufragen. Besteht das zur Diskussion ähnliche Punkte mit in den Zensus aufzunehmen?

Viele Grüße,

Ingo Schönwandt

> On 11. Mar 2020, at 15:34, info@destatis.de wrote:
>
> Statistisches Bundesamt
> Zentraler Auskunftsdienst
>
> Tel. +49 (0) 611 75 2405
> https://www.destatis.de/kontakt
>
> Sehr geehrter Herr Schönwandt,
>
> vielen Dank für Ihre Rückfrage vom 24. Februar 2020.
>
> Bitte beachten Sie im Folgenden unsere Rückmeldungen zu den von Ihnen genannten Fragepunkten:
>
> - Daten des Mikrozensus 2018:
> Eine tiefer regionalisierte Auswertung des Mikrozensus als die der regionalen Anpassungsschichten ist aus Datenschutzgründen (Geheimhaltung) leider nicht möglich.
>
> 1. Gebäudetyp/Wohnungsfläche <-> Energie-Label je Gebäude (gem. europäischer Energy Performance of Buildings Directive (EU/2018/844))
>
> Die von Ihnen gewünschten Daten liegen im Informationsangebot der amtlichen Statistik nicht vor.
>
> 2. Gebäudetyp/Wohnungsfläche <-> Nachträgliche Isolationsarbeiten (Fenster, Außenwand, Dachboden, Kellerdecke)
>
> Die von Ihnen gewünschten Daten liegen im Informationsangebot der amtlichen Statistik nicht vor.
>
> 3. Gebäudetyp/Wohnungsfläche <-> Energieverbrauch je Energiequelle in kWh/m2
>
> Die von Ihnen gewünschten Daten liegen im Informationsangebot der amtlichen Statistik nicht vor.
>
> 4. Gebäude mit erneuerbaren Energieanlagen ( Solar PV, Solarthermie, Geothermie, Wärmepumpe, Wind ) in Anzahl ~
>
> In unserer Antwort vom 20. Februar 2020 haben wir auf unsere Publikation des Mikrozensus "Wohnen in Deutschland - Zusatzprogramm des Mikrozensus 2018" verwiesen:
> https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Wohnen/_inhalt.html#sprg233558
> Hier finden Sie Daten zu verwendeten Energiearten der Beheizung und Warmwasserversorgung.
>
> Weitere Daten hierzu liegen im Informationsangebot der amtlichen Statistik nicht vor.
>
> 5. Gebäude mit erneuerbaren Energieanlagen ( Solar PV, Solarthermie, Geothermie, Wärmepumpe, Wind ) in kWpeak
>
> Die von Ihnen gewünschten Daten liegen im Informationsangebot der amtlichen Statistik nicht vor.
>
> 6. Produzierte erneuerbare Energie hinterm Zähler in kWh
>
> Die von Ihnen gewünschten Daten liegen im Informationsangebot der amtlichen Statistik nicht vor.
>
> Gerne möchten wir Sie auf folgende Seiten verweisen:
>
> - AG Energiebilanzen
> https://ag-energiebilanzen.de/
>
> - co2online
> https://www.co2online.de/

> Bei weiteren Fragen stehen wir Ihnen gern zur Verfügung.
> Bitte nutzen Sie dafür unser Kontaktformular https://www.destatis.de/kontakt/
>
> Mit freundlichen Grüßen
> Im Auftrag
>
> Marie-Louise Haider
>
> ______________________________________________________________________________________________________________________
> Zur Beantwortung Ihrer Anfrage haben wir die von Ihnen mitgeteilten personenbezogenen Daten gespeichert. Die Informationen und Hinweise zum Datenschutz nach Art. 13 der Datenschutzgrundverordnung (DS-GVO) finden Sie unter: https://www.destatis.de/DE/Service/Datenschutz/_inhalt.html.

**From:** **Nadine Walikewitz** nadine.walikewitz@co2online.de
**Subject:** Masterarbeit Energiewende Deutschland
**Date:** 11. February 2020 at 08:30
**To:** i.schonwandt@stud.uis.no
**Cc:** Sebastian Metzger Sebastian.metzger@CO2Online.de

---

Sehr geehrter Herr Schönwandt,

vielen Dank für Ihre Anfrage. Wir freuen uns über Ihr Interesse an unseren Daten.
Auf der Webseite www.wohngebaeude.info haben wir einen Großteil unserer Datenbank dargestellt. Ich denke Sie können hier einen guten Überblick bekommen, welche Daten wir haben. Unsere Daten stehen leider nur auf PLZ-Ebene zur Verfügung.
Bei Rückfragen stehe ich Ihnen gerne zur Verfügung.

Ihre Anfrage:

Sehr geehrter Herr Metzger,

auf Empfehlung von Danny Püschel von der Gebäude-Allianz bzw. dem NABU schreibe ich Ihnen bzgl. meiner Masterarbeit zum Thema Energiewende in Deutschland.

Ich bin Masterstudent an den Universitäten von Stavanger (NO) und Delft (NL) und möchte in meiner Abschlussarbeit untersuchen, welche externen Effekte und systemischen Hindernisse beim Umsetzen der Klimapolitik der Bundesregierung auftreten könnten, um so zu evaluieren in wie weit ihr Maßnahmenpaket robust ist, um die Klimaziele zu erreichen. Die Untersuchung befasst sich speziell mit den Sektoren Personenverkehr und Transport und basiert auf dem Erstellen eines Simulationsmodells der relevanten gesellschaftlichen Aspekte.

Bei diesem Ansatz bin ich auf eine relativ gute Datenlage angewiesen, damit das Gesellschaftssystem auch möglichst getreu nachgebildet werden kann. Bisher verlief meine Datenerhebung jedoch sehr schlecht. Ich suche besonders Daten zum Gebäudebestand auf Landkreisebene (wenn möglich), die Auskunft geben über Aspekte, wie u.a. Energieeffizienz, Baujahr, Energiequelle, Größe von Haushalten, Gebäudetyp/Bauart.

Wären Sie an Findungen von so einer Untersuchung interessiert und hätten Sie eventuell Zugang zu solchen Datensätzen? Alternativ wäre ich auch sehr Dankbar über Hinweise an wen ich mich diesbezüglich noch wenden könnte.

Viele Grüße aus Deft,

Ingo Schönwandt

Viele Grüße,

Nadine Walikewitz
-----------------------------------------

**Dr. Nadine Walikewitz**
Managerin Research

co2online gemeinnützige GmbH
Hochkirchstr. 9
10829 Berlin

Geschäftsführerin: Tanja Loitz
Amtsgericht Berlin Charlottenburg: HRB 91249 │ UStIDNr.: DE233964948

Tel.: +49 (30) 210 21 86- 18│ Fax: +49 (30) 76 76 85 – 11 │ E-Mail: nadine.walikewitz@co2online.de

**www.co2online.de** | **www.mein-klimaschutz.de** | **www.energiesparkonto.de**
**Twitter** | **Facebook** | **Instagram** | **Xing** | **Newsletter**

**From:** Fahrzeugstatistik@kba.de
**Subject:** AW: Statistiken_Kraftfahrzeuge AZ: 321-130-8375-19
**Date:** 24. September 2019 at 11:10
**To:** i.schonwandt@stud.uis.no

Sehr geehrter Herr Schönwandt,

anbei übersende ich Ihnen mein Antwortschreiben.

Mit freundlichen Grüßen
Im Auftrag

Berenice Pickardt

Kraftfahrt-Bundesamt
Fahrzeugstatistik
24932 Flensburg

Telefon: 0461 316-1133
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E-Mail: fahrzeugstatistik@kba.de
Internet: www.kba.de

Von: no-reply@kba.de
Gesendet: Mittwoch, 11. September 2019 02:48:01 (UTC+01:00) Amsterdam, Berlin, Bern, Rom, Stockholm, Wien
An: INFO
Betreff: Statistiken_Kraftfahrzeuge

Anrede: Herr
Vorname: Ingo
Nachname: Schönwandt
Firma:
PLZ:
Wohnort:
Strasse und Nr.:
Telefon:
Telefax:
E-Mail: i.schonwandt@stud.uis.no
Betreff_Text: Statistiken_Kraftfahrzeuge
Anliegen: Anregung:
Liebes KBA, gerne möchte ich anregen demnächst die Ladekapazität von Elektroautos und relevanten Hybridautos mit in die Bestandsdatenbank aufzunehmen. Elektrisch fahrende Autos haben keinen Hubraum, für ihre Fahrleistung und Attraktivität sind vielmehr die Reichweite ausschlaggebend, repräsentiert durch die Max Ladekapazität. Außerdem sind elektrische Fahrzeuge auch aufgrund ihrer Eigenschaft als mobile Batterien für das Stromnetz relevant. Falls ihr die Ladekapazität bald mit aufnehmt, würde ich mich über eine kurze Benachrichtigung freuen.

Viele Grüße,

Ingo Schönwandt
Datenschutz: $ja

# Kraftfahrt-Bundesamt

**Kraftfahrt-Bundesamt • 24932 Flensburg**

Herrn
Ingo Schönwandt

## E-Mail

i.schonwandt@stud.uis.no

Ihr Zeichen / Ihre Nachricht vom:
11.09.2019
Bei Antwort bitte angeben:
321-130/8375-19
Ansprechpartner(in):
Berenice Pickardt
Telefon: 0461 316-1133
Telefax: 0461 316-2833
E-Mail:
Fahrzeugstatistik@kba.de

Datum: 24. September 2019

Diesen Kurzbrief übersende ich mit der Bitte um

| | | | |
|---|---|---|---|
| ☒ Kenntnisnahme | ☐ Rückgabe | ☐ Preisangebot | ☐ Weiterleitung an: |
| ☐ Stellungnahme | ☐ Erledigung | ☐ weitere Veranlassung | ☐ |
| ☐ Prüfung | ☐ Teilnahme | ☐ Rücksprache/Ihren Anruf | ☐ Anlagen: |

Sehr geehrter Herr Schönwandt,

zunächst bedanke ich mich für ihre E-Mail und Ihr gezeigtes Interesse an den Statistiken des Kraftfahrt-Bundesamtes. Für die verzögerte Bearbeitung Ihrer Anfrage bitte ich um Verständnis.

Sie geben Anregungen zu den Statistiken des Kraftfahrt-Bundesamtes.

Ich bedanke mich für Ihre Anregungen zur Aufnahme der Ladekapazität von Personenkraftwagen mit dem Antrieb Elektro in den amtlichen Veröffentlichungen des Kraftfahrt-Bundesamtes. Die amtlichen Fahrzeugstatistiken werden vor allem aufgrund der Angaben in den Zulassungsdokumenten erstellt, die im Zentralen Fahrzeugregister gespeichert sind. Die Angabe zur Ladekapazität wird nicht aufgeführt. Aus diesem Grund ist eine Aufnahme der Ladekapazität derzeit nicht möglich.

Für eventuelle Fragen stehe ich Ihnen selbstverständlich gerne auch telefonisch zur Verfügung.

Mit freundlichen Grüßen
Im Auftrag

Berenice Pickardt

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24944 Flensburg

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0461 316-0

Telefax:
0461 316-1650 oder -1495

E-Mail:
kba@kba.de

Internet:
www.kba.de

Konto:
Deutsche Bundesbank, Filiale Hamburg
IBAN: DE18 2000 0000 0020 0010 66
BIC: MARKDEF1200

# Appendix G - Data collection and sources extract

The following tables constitute a consecutive collection of individual data points and sources index ordered by sector containing a broad overview about data related to energy transition topics. Some data points are more, some less specific to Germany, but some also indicate generally applicable characteristics, such as technology specific energy consumption characteristic values. Highlighted in green are those data points that are actually used to calibrate and validate the model.

## Table 1: Building sector

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 1 | buildings | building stock by age group per building type 1 or 2 family houses constructed before 1918 | 2200656 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 2 | buildings | building stock by age group per building type 1 or 2 family houses constructed before 1918 share of total | 0,148 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 3 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1918-1948 | 2045435 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 4 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1918-1948 share of total | 0,138 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 5 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1949-1957 | 1476720 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 6 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1949-1957 share of total | 0,099 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 7 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1958-1968 | 2357250 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 8 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1958-1968 share of total | 0,158 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 9 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1969-1978 | 1940167 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 10 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1969-1978 share of total | 0,13 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 11 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1979-1987 | 1585337 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 12 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1979-1987 share of total | 0,107 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 13 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1988-1993 | 777809 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 14 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1988-1993 share of total | 0,052 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 15 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1994-2001 | 1456447 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 16 | buildings | building stock by age group per building type 1 or 2 family houses constructed 1994-2001 share of total | 0,098 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 17 | buildings | building stock by age group per building type 1 or 2 family houses constructed 2002-2008 | 1044512 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 18 | buildings | building stock by age group per building type 1 or 2 family houses constructed 2002-2008 share of total | 0,07 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |

| | | | | | | |
|---|---|---|---|---|---|---|
| 19 | buildings | building stock by age group per building type 1 or 2 family houses constructed total | 14884333 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 20 | buildings | building stock by age group per building type 1 or 2 family houses constructed total share of total | 1 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 21 | buildings | building stock by age group per building type multifamily houses constructed before 1918 | 501102 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 22 | buildings | building stock by age group per building type multifamily houses constructed before 1918 share of total | 0,185 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 23 | buildings | building stock by age group per building type multifamily houses constructed 1918-1948 | 329602 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 24 | buildings | building stock by age group per building type multifamily houses constructed 1918-1948 share of total | 0,122 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 25 | buildings | building stock by age group per building type multifamily houses constructed 1949-1957 | 318743 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 26 | buildings | building stock by age group per building type multifamily houses constructed 1949-1957 share of total | 0,118 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 27 | buildings | building stock by age group per building type multifamily houses constructed 1958-1968 | 455859 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 28 | buildings | building stock by age group per building type multifamily houses constructed 1958-1968 share of total | 0,168 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 29 | buildings | building stock by age group per building type multifamily houses constructed 1969-1978 | 340280 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 30 | buildings | building stock by age group per building type multifamily houses constructed 1969-1978 share of total | 0,126 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 31 | buildings | building stock by age group per building type multifamily houses constructed 1979-1987 | 292086 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 32 | buildings | building stock by age group per building type multifamily houses constructed 1979-1987 share of total | 0,108 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 33 | buildings | building stock by age group per building type multifamily houses constructed 1988-1993 | 131304 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 34 | buildings | building stock by age group per building type multifamily houses constructed 1988-1993 share of total | 0,049 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 35 | buildings | building stock by age group per building type multifamily houses constructed 1994-2001 | 245208 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 36 | buildings | building stock by age group per building type multifamily houses constructed 1994-2001 share of total | 0,09 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 37 | buildings | building stock by age group per building type multifamily houses constructed 2002-2008 | 92664 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 38 | buildings | building stock by age group per building type multifamily houses constructed 2002-2008 share of total | 0,034 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |

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|---|---|---|---|---|---|---|
| 39 | buildings | building stock by age group per building type multifamily houses constructed total | 2706848 | amount | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 40 | buildings | building stock by age group per building type multifamily houses constructed total share of total | 1 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | better: see Mikrozensus2018!Tabelle_14 data |
| 41 | buildings | building stock constructed before 1918 multifamily houses share | 0,19 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 42 | buildings | building stock constructed before 1918 1 or 2 family houses share | 0,81 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 43 | buildings | building stock constructed 1918-1948 multifamily houses share | 0,14 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 44 | buildings | building stock constructed 1918-1948 1 or 2 family houses share | 0,86 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 45 | buildings | building stock constructed 1949-1957 multifamily houses share | 0,18 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 46 | buildings | building stock constructed 1949-1957 1 or 2 family houses share | 0,82 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 47 | buildings | building stock constructed 1958-1968 multifamily houses share | 0,16 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 48 | buildings | building stock constructed 1958-1968 1 or 2 family houses share | 0,84 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 49 | buildings | building stock constructed 1969-1978 multifamily houses share | 0,15 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 50 | buildings | building stock constructed 1969-1978 1 or 2 family houses share | 0,85 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 51 | buildings | building stock constructed 1979-1987 multifamily houses share | 0,16 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 52 | buildings | building stock constructed 1979-1987 1 or 2 family houses share | 0,84 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 53 | buildings | building stock constructed 1988-1993 multifamily houses share | 0,14 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 54 | buildings | building stock constructed 1988-1993 1 or 2 family houses share | 0,86 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 55 | buildings | building stock constructed 1994-2001 multifamily houses share | 0,14 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 56 | buildings | building stock constructed 1994-2001 1 or 2 family houses share | 0,86 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 57 | buildings | building stock constructed 2002-2008 multifamily houses share | 0,08 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |
| 58 | buildings | building stock constructed 2002-2008 1 or 2 family houses share | 0,92 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | generated / better: see Mikrozensus2018!Tabelle_14 data |

| | | | | | | |
|---|---|---|---|---|---|---|
| 59 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses before 1918 not modernized energy consumption characteristic value | 226,6 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 60 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses before 1918 not modernized share of total | 0,03 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 61 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses before 1918 little modernized energy consumption characteristic value | 197,1 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 62 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses before 1918 little modernized share of total | 0,64 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 63 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses before 1918 medium to well modernized energy consumption characteristic value | 167,4 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 64 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses before 1918 medium to well modernized share of total | 0,33 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 65 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1918-1948 not modernized energy consumption characteristic value | 237,5 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 66 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1918-1948 not modernized share of total | 0,02 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 67 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1918-1948 little modernized energy consumption characteristic value | 208,8 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 68 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1918-1948 little modernized share of total | 0,67 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 69 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1918-1948 medium to well modernized energy consumption characteristic value | 175,3 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 70 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1918-1948 medium to well modernized share of total | 0,31 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 71 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1949-1957 not modernized energy consumption characteristic value | 235,2 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 72 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1949-1957 not modernized share of total | 0,03 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 73 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1949-1957 little modernized energy consumption characteristic value | 209,8 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 74 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1949-1957 little modernized share of total | 0,73 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 75 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1949-1957 medium to well modernized energy consumption characteristic value | 175,4 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 76 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1949-1957 medium to well modernized share of total | 0,24 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 77 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1958-1968 not modernized energy consumption characteristic value | 231,9 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 78 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1958-1968 not modernized share of total | 0,05 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 79 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1958-1968 little modernized energy consumption characteristic value | 203,1 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 80 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1958-1968 little modernized share of total | 0,74 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |

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|---|---|---|---|---|---|---|
| 81 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1958-1968 medium to well modernized energy consumption characteristic value | 165,3 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 82 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1958-1968 medium to well modernized share of total | 0,21 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 83 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1969-1978 not modernized energy consumption characteristic value | 213,5 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 84 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1969-1978 not modernized share of total | 0,11 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 85 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1969-1978 little modernized energy consumption characteristic value | 187,6 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 86 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1969-1978 little modernized share of total | 0,74 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 87 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1969-1978 medium to well modernized energy consumption characteristic value | 154,7 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 88 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1969-1978 medium to well modernized share of total | 0,15 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 89 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1979-1987 not modernized energy consumption characteristic value | 168,9 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 90 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1979-1987 not modernized share of total | 0,29 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 91 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1979-1987 little modernized energy consumption characteristic value | 152,9 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 92 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1979-1987 little modernized share of total | 0,64 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 93 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1979-1987 medium to well modernized energy consumption characteristic value | 127,1 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 94 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1979-1987 medium to well modernized share of total | 0,07 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 95 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1988-1993 not modernized energy consumption characteristic value | 148,5 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 96 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1988-1993 not modernized share of total | 0,75 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 97 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1988-1993 little modernized energy consumption characteristic value | 135,7 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 98 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1988-1993 little modernized share of total | 0,2 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 99 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1988-1993 medium to well modernized energy consumption characteristic value | 111,1 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 100 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1988-1993 medium to well modernized share of total | 0,05 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 101 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1994-2001 not modernized energy consumption characteristic value | 116 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 102 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1994-2001 not modernized share of total | 0,85 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |

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|---|---|---|---|---|---|---|
| 103 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1994-2001 little modernized energy consumption characteristic value | 105,8 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 104 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1994-2001 little modernized share of total | 0,15 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 105 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1994-2001 medium to well modernized energy consumption characteristic value | 0,4242 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 106 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 1994-2001 medium to well modernized share of total | 0,004242 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 107 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 2002-2008 not modernized energy consumption characteristic value | 91,8 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 108 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 2002-2008 not modernized share of total | 0,95 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 109 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 2002-2008 little modernized energy consumption characteristic value | 84,9 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 110 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 2002-2008 little modernized share of total | 0,05 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 111 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 2002-2008 medium to well modernized energy consumption characteristic value | 0,4242 | kWh/(m2*a) | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | energy consumption incl. warm water heating |
| 112 | buildings | building stock level of modernization 2010 by age group 1 or 2 family houses 2002-2008 medium to well modernized share of total | 0,004242 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 113 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 wall insulation pre WSchV 1977 share | 0,815 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 114 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 wall insulation post WSchV 1977 1984 share | 0,053 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 115 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 wall insulation post WSchV 1995 share | 0,132 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 116 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 wall insulation pre WSchV 1977 share | 0,789 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 117 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 wall insulation post WSchV 1977 1984 share | 0,111 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 118 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 wall insulation post WSchV 1995 share | 0,1 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 119 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 wall insulation pre WSchV 1977 share | 0,866 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 120 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 wall insulation post WSchV 1977 1984 share | 0,012 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 121 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 wall insulation post WSchV 1995 share | 0,122 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 122 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 wall insulation pre WSchV 1977 share | 0,876 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 123 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 wall insulation post WSchV 1977 1984 share | 0,022 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 124 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 wall insulation post WSchV 1995 share | 0,102 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 125 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 wall insulation pre WSchV 1977 share | 0,898 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |
| 126 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 wall insulation post WSchV 1977 1984 share | 0,021 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |  |

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|---|---|---|---|---|---|
| 127 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 wall insulation post WSchV 1995 share | 0,081 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 128 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 wall insulation pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 129 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 wall insulation post WSchV 1977 1984 share | 0,95 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 130 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 wall insulation post WSchV 1995 share | 0,05 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 131 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 wall insulation pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 132 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 wall insulation post WSchV 1977 1984 share | 0,961 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 133 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 wall insulation post WSchV 1995 share | 0,039 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 134 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 roof insulation pre WSchV 1977 share | 0,342 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 135 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 roof insulation post WSchV 1977 1984 share | 0,434 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 136 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 roof insulation post WSchV 1995 share | 0,224 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 137 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 roof insulation pre WSchV 1977 share | 0,311 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 138 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 roof insulation post WSchV 1977 1984 share | 0,522 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 139 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 roof insulation post WSchV 1995 share | 0,167 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 140 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 roof insulation pre WSchV 1977 share | 0,427 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 141 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 roof insulation post WSchV 1977 1984 share | 0,427 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 142 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 roof insulation post WSchV 1995 share | 0,146 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 143 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 roof insulation pre WSchV 1977 share | 0,462 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 144 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 roof insulation post WSchV 1977 1984 share | 0,402 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 145 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 roof insulation post WSchV 1995 share | 0,136 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 146 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 roof insulation pre WSchV 1977 share | 0,53 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 147 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 roof insulation post WSchV 1977 1984 share | 0,343 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 148 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 roof insulation post WSchV 1995 share | 0,127 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 149 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 roof insulation pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 150 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 roof insulation post WSchV 1977 1984 share | 0,825 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 151 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 roof insulation post WSchV 1995 share | 0,175 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |

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| 152 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 roof insulation pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 153 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 roof insulation post WSchV 1977 1984 share | 0,874 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 154 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 roof insulation post WSchV 1995 share | 0,126 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 155 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 window glazing pre WSchV 1977 share | 0,164 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 156 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 window glazing post WSchV 1977 1984 share | 0,678 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 157 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 window glazing post WSchV 1995 share | 0,158 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 158 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 window glazing pre WSchV 1977 share | 0,183 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 159 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 window glazing post WSchV 1977 1984 share | 0,656 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 160 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 window glazing post WSchV 1995 share | 0,161 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 161 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 window glazing pre WSchV 1977 share | 0,267 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 162 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 window glazing post WSchV 1977 1984 share | 0,604 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 163 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 window glazing post WSchV 1995 share | 0,129 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 164 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 window glazing pre WSchV 1977 share | 0,355 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 165 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 window glazing post WSchV 1977 1984 share | 0,501 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 166 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 window glazing post WSchV 1995 share | 0,144 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 167 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 window glazing pre WSchV 1977 share | 0,531 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 168 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 window glazing post WSchV 1977 1984 share | 0,345 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 169 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 window glazing post WSchV 1995 share | 0,124 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 170 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 window glazing pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 171 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 window glazing post WSchV 1977 1984 share | 0,912 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 172 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 window glazing post WSchV 1995 share | 0,088 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 173 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 window glazing pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 174 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 window glazing post WSchV 1977 1984 share | 0,931 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 175 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 window glazing post WSchV 1995 share | 0,069 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 176 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 basement ceiling pre WSchV 1977 share | 0,934 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |

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| 177 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 basement ceiling post WSchV 1977 1984 share | 0,014 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 178 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 basement ceiling post WSchV 1995 share | 0,052 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 179 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 basement ceiling pre WSchV 1977 share | 0,944 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 180 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 basement ceiling post WSchV 1977 1984 share | 0,012 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 181 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 basement ceiling post WSchV 1995 share | 0,044 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 182 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 basement ceiling pre WSchV 1977 share | 0,951 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 183 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 basement ceiling post WSchV 1977 1984 share | 0,01 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 184 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949-1957 basement ceiling post WSchV 1995 share | 0,039 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 185 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 basement ceiling pre WSchV 1977 share | 0,957 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 186 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 basement ceiling post WSchV 1977 1984 share | 0,009 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 187 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958-1968 basement ceiling post WSchV 1995 share | 0,034 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 188 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 basement ceiling pre WSchV 1977 share | 0,969 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 189 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 basement ceiling post WSchV 1977 1984 share | 0,007 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 190 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969-1978 basement ceiling post WSchV 1995 share | 0,024 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 191 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 basement ceiling pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 192 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 basement ceiling post WSchV 1977 1984 share | 0,98 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 193 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979-1987 basement ceiling post WSchV 1995 share | 0,02 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 194 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 basement ceiling pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 195 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 basement ceiling post WSchV 1977 1984 share | 0,985 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 196 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988-1993 basement ceiling post WSchV 1995 share | 0,015 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 197 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 heating system pre WSchV 1977 share | 0,119 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 198 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 heating system post WSchV 1977 1984 share | 0,155 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 199 | buildings | building stock insulation standard of 1 or 2 family houses by age group before 1918 heating system post WSchV 1995 share | 0,726 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 200 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 heating system pre WSchV 1977 share | 0,114 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |
| 201 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918-1948 heating system post WSchV 1977 1984 share | 0,271 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf |

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| 202 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1918–1948 heating system post WSchV 1995 share | 0,615 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 203 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949–1957 heating system pre WSchV 1977 share | 0,146 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 204 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949–1957 heating system post WSchV 1977 1984 share | 0,321 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 205 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1949–1957 heating system post WSchV 1995 share | 0,533 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 206 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958–1968 heating system pre WSchV 1977 share | 0,126 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 207 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958–1968 heating system post WSchV 1977 1984 share | 0,329 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 208 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1958–1968 heating system post WSchV 1995 share | 0,545 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 209 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969–1978 heating system pre WSchV 1977 share | 0,115 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 210 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969–1978 heating system post WSchV 1977 1984 share | 0,357 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 211 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1969–1978 heating system post WSchV 1995 share | 0,528 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 212 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979–1987 heating system pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 213 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979–1987 heating system post WSchV 1977 1984 share | 0,516 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 214 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1979–1987 heating system post WSchV 1995 share | 0,484 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 215 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988–1993 heating system pre WSchV 1977 share | 0 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 216 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988–1993 heating system post WSchV 1977 1984 share | 0,825 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 217 | buildings | building stock insulation standard of 1 or 2 family houses by age group 1988–1993 heating system post WSchV 1995 share | 0,175 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | |
| 218 | buildings | buildings modernizing activity by owner occupied and private ownership basement ceiling and walls share of total | 0,054 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: modernizing min 25% of component |
| 219 | buildings | buildings modernizing activity by owner occupied and private ownership wall insulation share of total | 0,099 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: modernizing min 25% of component |
| 220 | buildings | buildings modernizing activity by owner occupied and private ownership roof insulation share of total | 0,201 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: modernizing 100% of component |
| 221 | buildings | buildings modernizing activity by owner occupied and private ownership window glazing share of total | 0,238 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: modernizing min 10% of component |
| 222 | buildings | buildings modernizing activity by owner occupied and private ownership heating system share of total | 0,246 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: replacing the heating system |
| 223 | buildings | buildings modernizing activity by owner occupied and private ownership water heating share of total | 0,157 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: replacing water heating system |
| 224 | buildings | buildings modernizing activity by owner occupied and private ownership air conditioning share of total | 0,005 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: replacing or installing air conditioning system |

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|---|---|---|---|---|---|---|
| 225 | buildings | buildings modernizing activity by commercial housing provider basement ceiling and walls share of total | 0,155 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: modernizing min 25% of component |
| 226 | buildings | buildings modernizing activity by commercial housing provider wall insulation share of total | 0,132 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: modernizing min 25% of component |
| 227 | buildings | buildings modernizing activity by commercial housing provider roof insulation share of total | 0,274 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: modernizing 100% of component |
| 228 | buildings | buildings modernizing activity by commercial housing provider window glazing share of total | 0,135 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: modernizing min 10% of component |
| 229 | buildings | buildings modernizing activity by commercial housing provider heating system share of total | 0,164 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: replacing the heating system |
| 230 | buildings | buildings modernizing activity by commercial housing provider water heating share of total | 0,119 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: replacing water heating system |
| 231 | buildings | buildings modernizing activity by commercial housing provider air conditioning share of total | 0,021 | 1/100 | https://www.iwu.de/fileadmin/user_upload/dateien/energie/ake48/IWU-Tagung_2012-05-31_Walberg_ARGE_Energieverbrauchskennwerte.pdf | equals: replacing or installing air conditioning system |
| 232 | buildings | heating energy demand constructed 1970-1980 yearly avg min | 200 | kWh/(m2*a) | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 233 | buildings | heating energy demand constructed 1970-1980 yearly avg max | 300 | kWh/(m2*a) | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 234 | buildings | heating energy demand constructed 1980-1990 yearly avg min | 125 | kWh/(m2*a) | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 235 | buildings | heating energy demand constructed 1980-1990 yearly avg max | 200 | kWh/(m2*a) | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 236 | buildings | heating energy demand constructed 1990-2000 yearly avg min | 90 | kWh/(m2*a) | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 237 | buildings | heating energy demand constructed 1990-2000 yearly avg max | 125 | kWh/(m2*a) | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 238 | buildings | heating energy demand constructed after 2000 yearly avg min | 25 | kWh/(m2*a) | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 239 | buildings | heating energy demand constructed after 2000 yearly avg max | 90 | kWh/(m2*a) | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 240 | buildings | heating energy demand by standard EnEV reference low-energy house max | 75 | kWh/(m2*a) | https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 241 | buildings | heating energy demand by standard KfW efficiency house 55 max | 58 | kWh/(m2*a) | https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 242 | buildings | heating energy demand by standard 3 liter house max | 35 | kWh/(m2*a) | https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 243 | buildings | heating energy demand by standard KfW efficiency house 40 max | 24 | kWh/(m2*a) | https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 244 | buildings | heating energy demand by standard passive house max | 15 | kWh/(m2*a) | https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 245 | buildings | heating energy demand by standard zero energy house max avg | 0 | kWh/(m2*a) | https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 246 | buildings | heating energy demand by standard plus energy house max avg | -1 | kWh/(m2*a) | https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 247 | buildings | EU-EPB directive_NZEB from 1.1.2019 for public buildings | 24 | kWh/(m2*a) | https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en | https://energie-m.de/info/geg-2020.html |
| 248 | buildings | EU-EPB directive_NZEB from 1.1.2021 for all | 24 | kWh/(m2*a) | https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en | https://energie-m.de/info/geg-2020.html |
| 249 | buildings | housing type relative energy efficiency gallery house | 0,4 | dml | https://www.effizienzhaus-online.de/waermedaemmung | |
| 250 | buildings | housing type relative energy efficiency townhouse | 0,6 | dml | https://www.effizienzhaus-online.de/waermedaemmung | |
| 251 | buildings | housing type relative energy efficiency semidetached house | 0,8 | dml | https://www.effizienzhaus-online.de/waermedaemmung | |
| 252 | buildings | housing type relative energy efficiency detached house | 1 | dml | https://www.effizienzhaus-online.de/waermedaemmung | |
| 253 | buildings | energy demand characteristic value of buildings 1 dwelling constructed before 1919 | 247 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 254 | buildings | energy demand characteristic value of buildings 1 dwelling constructed 1919-1948 | 254 | kWh/(m2*a) | Bigalke et al. (2016) | |

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|---|---|---|---|---|---|
| 255 | buildings | energy demand characteristic value of buildings 1 dwelling constructed 1949–1978 | 236 | kWh/(m2*a) | Bigalke et al. (2016) |
| 256 | buildings | energy demand characteristic value of buildings 1 dwelling constructed 1979–1990 | 175 | kWh/(m2*a) | Bigalke et al. (2016) |
| 257 | buildings | energy demand characteristic value of buildings 1 dwelling constructed 1991–2000 | 131 | kWh/(m2*a) | Bigalke et al. (2016) |
| 258 | buildings | energy demand characteristic value of buildings 1 dwelling constructed 2001–2008 | 83 | kWh/(m2*a) | Bigalke et al. (2016) |
| 259 | buildings | energy demand characteristic value of buildings 1 dwelling constructed 2009–2020 | 48 | kWh/(m2*a) | Bigalke et al. (2016) |
| 260 | buildings | energy demand characteristic value of buildings 1 dwelling constructed 2021 and later | 24 | kWh/(m2*a) | EU-EPBD + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ |
| 261 | buildings | energy demand characteristic value of buildings 1 dwelling average | 190 | kWh/(m2*a) | Bigalke et al. (2016) |
| 262 | buildings | energy demand characteristic value of buildings 2 dwellings constructed before 1919 | 238 | kWh/(m2*a) | Bigalke et al. (2016) |
| 263 | buildings | energy demand characteristic value of buildings 2 dwellings constructed 1919–1948 | 236 | kWh/(m2*a) | Bigalke et al. (2016) |
| 264 | buildings | energy demand characteristic value of buildings 2 dwellings constructed 1949–1978 | 219 | kWh/(m2*a) | Bigalke et al. (2016) |
| 265 | buildings | energy demand characteristic value of buildings 2 dwellings constructed 1979–1990 | 168 | kWh/(m2*a) | Bigalke et al. (2016) |
| 266 | buildings | energy demand characteristic value of buildings 2 dwellings constructed 1991–2000 | 127 | kWh/(m2*a) | Bigalke et al. (2016) |
| 267 | buildings | energy demand characteristic value of buildings 2 dwellings constructed 2001–2008 | 88 | kWh/(m2*a) | Bigalke et al. (2016) |
| 268 | buildings | energy demand characteristic value of buildings 2 dwellings constructed 2009–2020 | 46 | kWh/(m2*a) | Bigalke et al. (2016) |
| 269 | buildings | energy demand characteristic value of buildings 2 dwelling constructed 2021 and later | 24 | kWh/(m2*a) | EU-EPBD + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ |
| 270 | buildings | energy demand characteristic value of buildings 2 dwellings average | 198 | kWh/(m2*a) | Bigalke et al. (2016) |
| 271 | buildings | energy demand characteristic value of buildings 3–6 dwellings constructed before 1919 | 212 | kWh/(m2*a) | Bigalke et al. (2016) |
| 272 | buildings | energy demand characteristic value of buildings 3–6 dwellings constructed 1919–1948 | 211 | kWh/(m2*a) | Bigalke et al. (2016) |
| 273 | buildings | energy demand characteristic value of buildings 3–6 dwellings constructed 1949–1978 | 192 | kWh/(m2*a) | Bigalke et al. (2016) |
| 274 | buildings | energy demand characteristic value of buildings 3–6 dwellings constructed 1979–1990 | 155 | kWh/(m2*a) | Bigalke et al. (2016) |
| 275 | buildings | energy demand characteristic value of buildings 3–6 dwellings constructed 1991–2000 | 127 | kWh/(m2*a) | Bigalke et al. (2016) |
| 276 | buildings | energy demand characteristic value of buildings 3–6 dwellings constructed 2001–2008 | 80 | kWh/(m2*a) | Bigalke et al. (2016) |
| 277 | buildings | energy demand characteristic value of buildings 3–6 dwellings constructed 2009–2020 | 46 | kWh/(m2*a) | Bigalke et al. (2016) |
| 278 | buildings | energy demand characteristic value of buildings 3–6 dwelling constructed 2021 and later | 24 | kWh/(m2*a) | EU-EPBD + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ |
| 279 | buildings | energy demand characteristic value of buildings 3–6 dwellings average | 179 | kWh/(m2*a) | Bigalke et al. (2016) |
| 280 | buildings | energy demand characteristic value of buildings 7–12 dwellings constructed before 1919 | 182 | kWh/(m2*a) | Bigalke et al. (2016) |
| 281 | buildings | energy demand characteristic value of buildings 7–12 dwellings constructed 1919–1948 | 178 | kWh/(m2*a) | Bigalke et al. (2016) |
| 282 | buildings | energy demand characteristic value of buildings 7–12 dwellings constructed 1949–1978 | 166 | kWh/(m2*a) | Bigalke et al. (2016) |
| 283 | buildings | energy demand characteristic value of buildings 7–12 dwellings constructed 1979–1990 | 152 | kWh/(m2*a) | Bigalke et al. (2016) |
| 284 | buildings | energy demand characteristic value of buildings 7–12 dwellings constructed 1991–2000 | 114 | kWh/(m2*a) | Bigalke et al. (2016) |
| 285 | buildings | energy demand characteristic value of buildings 7–12 dwellings constructed 2001–2008 | 76 | kWh/(m2*a) | Bigalke et al. (2016) |
| 286 | buildings | energy demand characteristic value of buildings 7–12 dwellings constructed 2009–2020 | 53 | kWh/(m2*a) | Bigalke et al. (2016) |

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| 287 | buildings | energy demand characteristic value of buildings 7-12 dwelling constructed 2021 and later | 24 | kWh/(m2*a) | EU-EPBD + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 288 | buildings | energy demand characteristic value of buildings 7-12 dwellings average | 155 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 289 | buildings | energy demand characteristic value of buildings 13 and more dwellings constructed before 1919 | 169 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 290 | buildings | energy demand characteristic value of buildings 13 and more dwellings constructed 1919-1948 | 153 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 291 | buildings | energy demand characteristic value of buildings 13 and more dwellings constructed 1949-1978 | 140 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 292 | buildings | energy demand characteristic value of buildings 13 and more dwellings constructed 1979-1990 | 118 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 293 | buildings | energy demand characteristic value of buildings 13 and more dwellings constructed 1991-2000 | 101 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 294 | buildings | energy demand characteristic value of buildings 13 and more dwellings constructed 2001-2008 | 69 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 295 | buildings | energy demand characteristic value of buildings 13 and more dwellings constructed 2009-2020 | 54 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 296 | buildings | energy demand characteristic value of buildings 13 and more dwelling constructed 2021 and later | 24 | kWh/(m2*a) | EU-EPBD + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ + https://nei-dt.de/fachinformationen/neubau-standards/enev-referenzgebaeude/ | |
| 297 | buildings | energy demand characteristic value of buildings 13 and more dwellings average | 131 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 298 | buildings | energy demand characteristic value of detached and semidetached houses of heating oil | 225 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 299 | buildings | energy demand characteristic value of detached and semidetached houses of electricity | 198 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 300 | buildings | energy demand characteristic value of detached and semidetached houses of gas | 186 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 301 | buildings | energy demand characteristic value of detached and semidetached houses of wood incl pellets | 179 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 302 | buildings | energy demand characteristic value of detached and semidetached houses of district heating | 142 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 303 | buildings | energy demand characteristic value of detached and semidetached houses of heat pumps | 28 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 304 | buildings | energy demand characteristic value of townhouses and gallery flats houses of heating oil | 194 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 305 | buildings | energy demand characteristic value of townhouses and gallery flats houses of electricity | 145 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 306 | buildings | energy demand characteristic value of townhouses and gallery flats houses of gas | 163 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 307 | buildings | energy demand characteristic value of townhouses and gallery flats houses of wood incl pellets | 141 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 308 | buildings | energy demand characteristic value of townhouses and gallery flats houses of district heating | 124 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 309 | buildings | energy demand characteristic value of townhouses and gallery flats houses of heat pumps | 30 | kWh/(m2*a) | Bigalke et al. (2016) | |
| 310 | buildings | energy demand actual value of buildings 1 dwelling constructed before 1919 | 160 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 311 | buildings | energy demand actual value of buildings 1 dwelling constructed 1919-1948 | 163 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 312 | buildings | energy demand actual value of buildings 1 dwelling constructed 1949-1978 | 160 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 313 | buildings | energy demand actual value of buildings 1 dwelling constructed 1979-1990 | 139 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 314 | buildings | energy demand actual value of buildings 1 dwelling constructed 1991-2000 | 114 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 315 | buildings | energy demand actual value of buildings 1 dwelling constructed 2001-2008 | 85 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 316 | buildings | energy demand actual value of buildings 1 dwelling constructed 2009-2020 | 50 | kWh/(m2*a) | Bigalke et al. (2016) | assumption |
| 317 | buildings | energy demand actual value of buildings 1 dwelling constructed 2021later | 24 | kWh/(m2*a) | Bigalke et al. (2016) | as per EU directive |
| 318 | buildings | energy demand actual value of buildings 1 dwelling average | 141 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 319 | buildings | energy demand actual value of buildings 2 dwellings constructed before 1919 | 152 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |

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|---|---|---|---|---|---|---|
| 320 | buildings | energy demand actual value of buildings 2 dwellings constructed 1919-1948 | 149 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 321 | buildings | energy demand actual value of buildings 2 dwellings constructed 1949-1978 | 152 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 322 | buildings | energy demand actual value of buildings 2 dwellings constructed 1979-1990 | 132 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 323 | buildings | energy demand actual value of buildings 2 dwellings constructed 1991-2000 | 109 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 324 | buildings | energy demand actual value of buildings 2 dwellings constructed 2001-2008 | 82 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 325 | buildings | energy demand actual value of buildings 2 dwellings constructed 2009-2020 | 52 | kWh/(m2*a) | Bigalke et al. (2016) | assumption |
| 326 | buildings | energy demand actual value of buildings 2 dwellings constructed 2021later | 24 | kWh/(m2*a) | Bigalke et al. (2016) | as per EU directive |
| 327 | buildings | energy demand actual value of buildings 2 dwellings average | 141 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 328 | buildings | energy demand actual value of buildings 3-6 dwellings constructed before 1919 | 141 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 329 | buildings | energy demand actual value of buildings 3-6 dwellings constructed 1919-1948 | 136 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 330 | buildings | energy demand actual value of buildings 3-6 dwellings constructed 1949-1978 | 137 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 331 | buildings | energy demand actual value of buildings 3-6 dwellings constructed 1979-1990 | 127 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 332 | buildings | energy demand actual value of buildings 3-6 dwellings constructed 1991-2000 | 113 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 333 | buildings | energy demand actual value of buildings 3-6 dwellings constructed 2001-2008 | 86 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 334 | buildings | energy demand actual value of buildings 3-6 dwellings constructed 2009-2020 | 52 | kWh/(m2*a) | Bigalke et al. (2016) | assumption |
| 335 | buildings | energy demand actual value of buildings 3-6 dwellings constructed 2021later | 24 | kWh/(m2*a) | Bigalke et al. (2016) | as per EU directive |
| 336 | buildings | energy demand actual value of buildings 3-6 dwellings average | 132 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 337 | buildings | energy demand actual value of buildings 7-12 dwellings constructed before 1919 | 129 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 338 | buildings | energy demand actual value of buildings 7-12 dwellings constructed 1919-1948 | 122 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 339 | buildings | energy demand actual value of buildings 7-12 dwellings constructed 1949-1978 | 135 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 340 | buildings | energy demand actual value of buildings 7-12 dwellings constructed 1979-1990 | 152 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 341 | buildings | energy demand actual value of buildings 7-12 dwellings constructed 1991-2000 | 105 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 342 | buildings | energy demand actual value of buildings 7-12 dwellings constructed 2001-2008 | 86 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 343 | buildings | energy demand actual value of buildings 7-12 dwellings constructed 2009-2020 | 63 | kWh/(m2*a) | Bigalke et al. (2016) | assumption |
| 344 | buildings | energy demand actual value of buildings 7-12 dwellings constructed 2021later | 24 | kWh/(m2*a) | Bigalke et al. (2016) | as per EU directive |
| 345 | buildings | energy demand actual value of buildings 7-12 dwellings average | 130 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 346 | buildings | energy demand actual value of buildings 13 and more dwellings constructed before 1919 | 114 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 347 | buildings | energy demand actual value of buildings 13 and more dwellings constructed 1919-1948 | 113 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 348 | buildings | energy demand actual value of buildings 13 and more dwellings constructed 1949-1978 | 123 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 349 | buildings | energy demand actual value of buildings 13 and more dwellings constructed 1979-1990 | 109 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 350 | buildings | energy demand actual value of buildings 13 and more dwellings constructed 1991-2000 | 98 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 351 | buildings | energy demand actual value of buildings 13 and more dwellings constructed 2001-2008 | 85 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 352 | buildings | energy demand actual value of buildings 13 and more dwellings constructed 2009-2020 | 70 | kWh/(m2*a) | Bigalke et al. (2016) | assumption |
| 353 | buildings | energy demand actual value of buildings 13 and more dwellings constructed 2021later | 24 | kWh/(m2*a) | Bigalke et al. (2016) | as per EU directive |

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|---|---|---|---|---|---|---|
| 354 | buildings | energy demand actual value of buildings 13 and more dwellings average | 115 | kWh/(m2*a) | Bigalke et al. (2016) | IMPORTED |
| 355 | buildings | energy costs 2016 private households space heating | 29,6 | bn€ | Bigalke et al. (2016) | |
| 356 | buildings | energy costs 2016 private households hot water | 9,4 | bn€ | Bigalke et al. (2016) | |
| 357 | buildings | energy costs 2016 private households lighting | 3,2 | bn€ | Bigalke et al. (2016) | |
| 358 | buildings | energy costs 2016 private households air conditioning | 0,4242 | bn€ | Bigalke et al. (2016) | |
| 359 | buildings | energy costs 2016 industry space heating | 1,9 | bn€ | Bigalke et al. (2016) | |
| 360 | buildings | energy costs 2016 industry hot water | 0,6 | bn€ | Bigalke et al. (2016) | |
| 361 | buildings | energy costs 2016 industry lighting | 1,4 | bn€ | Bigalke et al. (2016) | |
| 362 | buildings | energy costs 2016 industry air conditioning | 0,7 | bn€ | Bigalke et al. (2016) | |
| 363 | buildings | energy costs 2016 trade commerce services space heating | 10 | bn€ | Bigalke et al. (2016) | |
| 364 | buildings | energy costs 2016 trade commerce services hot water | 1,4 | bn€ | Bigalke et al. (2016) | |
| 365 | buildings | energy costs 2016 trade commerce services lighting | 7,4 | bn€ | Bigalke et al. (2016) | |
| 366 | buildings | energy costs 2016 trade commerce services air conditioning | 0,5 | bn€ | Bigalke et al. (2016) | |
| 367 | buildings | heating sources of existing buildings with gas share | 0,8 | 1/100 | Bigalke et al. (2016) | |
| 368 | buildings | heating sources of existing buildings with heating oil share | 0,11 | 1/100 | Bigalke et al. (2016) | |
| 369 | buildings | heating sources of existing buildings with solar share | 0 | 1/100 | Bigalke et al. (2016) | |
| 370 | buildings | heating sources of existing buildings with electricity share | 0 | 1/100 | Bigalke et al. (2016) | |
| 371 | buildings | heating sources of existing buildings with district heating share | 0 | 1/100 | Bigalke et al. (2016) | |
| 372 | buildings | heating sources of existing buildings with heat pumps share | 0,04 | 1/100 | Bigalke et al. (2016) | |
| 373 | buildings | heating sources of existing buildings with biomass and others share | 0,05 | 1/100 | Bigalke et al. (2016) | |
| 374 | buildings | heating sources of new buildings with gas share | 0,51 | 1/100 | Bigalke et al. (2016) | |
| 375 | buildings | heating sources of new buildings with heating oil share | 0,02 | 1/100 | Bigalke et al. (2016) | |
| 376 | buildings | heating sources of new buildings with solar share | 0,01 | 1/100 | Bigalke et al. (2016) | |
| 377 | buildings | heating sources of new buildings with electricity share | 0,01 | 1/100 | Bigalke et al. (2016) | |
| 378 | buildings | heating sources of new buildings with district heating share | 0,08 | 1/100 | Bigalke et al. (2016) | |
| 379 | buildings | heating sources of new buildings with heat pumps share | 0,3 | 1/100 | Bigalke et al. (2016) | |
| 380 | buildings | heating sources of new buildings with biomass and others share | 0,07 | 1/100 | Bigalke et al. (2016) | |
| 381 | buildings | energy carrier primary source in dwellings gas share | 0,49 | 1/100 | Bigalke et al. (2016) | |
| 382 | buildings | energy carrier primary source in dwellings heating oil share | 0,27 | 1/100 | Bigalke et al. (2016) | |
| 383 | buildings | energy carrier primary source in dwellings electricity share | 0,03 | 1/100 | Bigalke et al. (2016) | |
| 384 | buildings | energy carrier primary source in dwellings district heating share | 0,14 | 1/100 | Bigalke et al. (2016) | |
| 385 | buildings | energy carrier primary source in dwellings heat pump share | 0,02 | 1/100 | Bigalke et al. (2016) | |
| 386 | buildings | energy carrier primary source in dwellings others share | 0,06 | 1/100 | Bigalke et al. (2016) | |
| 387 | buildings | energy efficiency improvement rate average 2005-2008 pa | 0,008 | 1/100 | Bigalke et al. (2016) | |
| 388 | buildings | energy efficiency improvement target rate pa | 0,02 | 1/100 | Bigalke et al. (2016) | |
| 389 | buildings | energy efficiency improvement rate 2005-2008 pa detached and semidetached houses wall insulation | 0,008 | 1/100 | Bigalke et al. (2016) | |

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| 390 | buildings | energy efficiency improvement rate 2005-2008 pa detached and semidetached houses roof insulation | 0,015 | 1/100 | Bigalke et al. (2016) |
| 391 | buildings | energy efficiency improvement rate 2005-2008 pa detached and semidetached houses floor insulation | 0,003 | 1/100 | Bigalke et al. (2016) |
| 392 | buildings | energy efficiency improvement rate 2005-2008 pa townhouses and gallery flats wall insulation | 0,008 | 1/100 | Bigalke et al. (2016) |
| 393 | buildings | energy efficiency improvement rate 2005-2008 pa townhouses and gallery flats roof insulation | 0,015 | 1/100 | Bigalke et al. (2016) |
| 394 | buildings | energy efficiency improvement rate 2005-2008 pa townhouses and gallery flats floor insulation | 0,003 | 1/100 | Bigalke et al. (2016) |
| 395 | buildings | window glazing stock 2015 total estimate | 605 | mio | Bigalke et al. (2016) |
| 396 | buildings | window glazing stock 2015 single glazing estimate | 19,6 | mio | Bigalke et al. (2016) |
| 397 | buildings | window glazing stock 2015 single glazing estimate share | 0,03 | 1/100 | Bigalke et al. (2016) |
| 398 | buildings | window glazing stock 2015 laminated and box windows estimate | 44,8 | mio | Bigalke et al. (2016) |
| 399 | buildings | window glazing stock 2015 laminated and box windows estimate share | 0,07 | 1/100 | Bigalke et al. (2016) |
| 400 | buildings | window glazing stock 2015 uncoated insulating glas estimate | 207,3 | mio | Bigalke et al. (2016) |
| 401 | buildings | window glazing stock 2015 uncoated insulating glas estimate share | 0,34 | 1/100 | Bigalke et al. (2016) |
| 402 | buildings | window glazing stock 2015 double glazing low e estimate | 284,2 | mio | Bigalke et al. (2016) |
| 403 | buildings | window glazing stock 2015 double glazing low e estimate share | 0,47 | 1/100 | Bigalke et al. (2016) |
| 404 | buildings | window glazing stock 2015 triple glazing low e estimate | 48,9 | mio | Bigalke et al. (2016) |
| 405 | buildings | window glazing stock 2015 triple glazing low e estimate share | 0,08 | 1/100 | Bigalke et al. (2016) |
| 406 | buildings | energy label by consumption classification Aplus min | -9999 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 407 | buildings | energy label by consumption classification Aplus max | 29,99 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 408 | buildings | energy label by consumption classification A min | 30 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 409 | buildings | energy label by consumption classification A max | 49,99 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 410 | buildings | energy label by consumption classification B min | 50 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 411 | buildings | energy label by consumption classification B max | 74,99 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 412 | buildings | energy label by consumption classification C min | 75 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 413 | buildings | energy label by consumption classification C max | 99,99 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 414 | buildings | energy label by consumption classification D min | 100 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 415 | buildings | energy label by consumption classification D max | 129,99 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 416 | buildings | energy label by consumption classification E min | 130 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 417 | buildings | energy label by consumption classification E max | 159,99 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 418 | buildings | energy label by consumption classification F min | 160 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 419 | buildings | energy label by consumption classification F max | 199,99 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 420 | buildings | energy label by consumption classification G min | 200 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 421 | buildings | energy label by consumption classification G max | 249,99 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 422 | buildings | energy label by consumption classification H min | 250 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 423 | buildings | energy label by consumption classification H max | 9999 | kWh/(m2*a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |
| 424 | buildings | energy label by energy costs classification Aplus min | -2 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse |

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| 425 | buildings | energy label by energy costs classification Aplus max | 2 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 426 | buildings | energy label by energy costs classification A | 2 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 427 | buildings | energy label by energy costs classification B | 3 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 428 | buildings | energy label by energy costs classification C | 4 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 429 | buildings | energy label by energy costs classification D | 6 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 430 | buildings | energy label by energy costs classification E | 7 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 431 | buildings | energy label by energy costs classification F | 9 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 432 | buildings | energy label by energy costs classification G | 11 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 433 | buildings | energy label by energy costs classification H | 13 | €/(m2a) | https://www.effizienzhaus-online.de/energieeffizienzklasse | |
| 434 | buildings | window glazing sales volume for new buildings 2015 | 5,3 | mio | Bigalke et al. (2016) | |
| 435 | buildings | window glazing sales volume for improving buildings 2015 | 8,6 | mio | Bigalke et al. (2016) | |
| 436 | buildings | insulation materials sales volume 2015 total | 37402 | 1000m3 | Bigalke et al. (2016) | |
| 437 | buildings | insulation materials sales volume 2015 nonresidential buildings | 13951 | 1000m3 | Bigalke et al. (2016) | |
| 438 | buildings | insulation materials sales volume 2015 residential buildings | 23451 | 1000m3 | Bigalke et al. (2016) | |
| 439 | buildings | insulation materials sales volume 2015 new buildings | 21506 | 1000m3 | Bigalke et al. (2016) | |
| 440 | buildings | insulation materials sales volume 2015 existing buildings | 15896 | 1000m3 | Bigalke et al. (2016) | |
| 441 | buildings | insulation materials sales volume 2015 roof insulation | 12492 | 1000m3 | Bigalke et al. (2016) | |
| 442 | buildings | insulation materials sales volume 2015 outer wall insulation | 12231 | 1000m3 | Bigalke et al. (2016) | |
| 443 | buildings | insulation materials sales volume 2015 inner wall insulation | 3142 | 1000m3 | Bigalke et al. (2016) | |
| 444 | buildings | insulation materials sales volume 2015 floor insulation | 4825 | 1000m3 | Bigalke et al. (2016) | |
| 445 | buildings | insulation materials sales volume 2015 other insulation | 4713 | 1000m3 | Bigalke et al. (2016) | |
| 446 | buildings | insulation materials sales volume 2015 fiberglass | 6052 | 1000m3 | Bigalke et al. (2016) | |
| 447 | buildings | insulation materials sales volume 2015 rockwool | 9852 | 1000m3 | Bigalke et al. (2016) | |
| 448 | buildings | insulation materials sales volume 2015 expanding polystyrol eps | 12156 | 1000m3 | Bigalke et al. (2016) | |
| 449 | buildings | insulation materials sales volume 2015 estruding polystyrol xps | 3553 | 1000m3 | Bigalke et al. (2016) | |
| 450 | buildings | insulation materials sales volume 2015 polyurethan polyisocyanurate pur pir | 1608 | 1000m3 | Bigalke et al. (2016) | |
| 451 | buildings | insulation materials sales volume 2015 wood | 1676 | 1000m3 | Bigalke et al. (2016) | |
| 452 | buildings | insulation materials sales volume 2015 others | 2506 | 1000m3 | Bigalke et al. (2016) | |
| 453 | buildings | dwellings owned by private persons total share | 0,585 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 454 | buildings | dwellings owned by private persons of which owneroccupied share | 0,571 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 455 | buildings | dwellings owned by private persons of which rented out share | 0,387 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 456 | buildings | dwellings owned by private persons of which vacant share | 0,042 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 457 | buildings | dwellings owned by community association total share | 0,221 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |

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| 458 | buildings | dwellings owned by community association of which owneroccupied share | 0,418 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 459 | buildings | dwellings owned by community association of which rented out share | 0,55 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 460 | buildings | dwellings owned by community association of which vacant share | 0,032 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 461 | buildings | dwellings owned by private organizations total share | 0,078 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 462 | buildings | dwellings owned by private organizations of which owneroccupied share | 0 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 463 | buildings | dwellings owned by private organizations of which rented out share | 0,933 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 464 | buildings | dwellings owned by private organizations of which vacant share | 0,067 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 465 | buildings | dwellings owned by housing cooperative total share | 0,051 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 466 | buildings | dwellings owned by housing cooperative of which owneroccupied share | 0 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 467 | buildings | dwellings owned by housing cooperative of which rented out share | 0,947 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 468 | buildings | dwellings owned by housing cooperative of which vacant share | 0,053 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 469 | buildings | dwellings owned by public organization total share | 0,064 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 470 | buildings | dwellings owned by public organizations of which owneroccupied share | 0 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 471 | buildings | dwellings owned by public organizations of which rented out share | 0,917 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 472 | buildings | dwellings owned by public organizations of which vacant share | 0,083 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 473 | buildings | dwellings in detached and semidetached houses total share | 0,464 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 474 | buildings | dwellings in townhouses and gallery flats total share | 0,536 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 475 | buildings | dwellings in detached and semidetached houses of which owned by private persons share | 0,307 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 476 | buildings | dwellings in detached and semidetached houses of which owned by community association share | 0,351 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 477 | buildings | dwellings in detached and semidetached houses of which owned by private organizations share | 0,136 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 478 | buildings | dwellings in detached and semidetached houses of which owned by housing cooperative share | 0,093 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 479 | buildings | dwellings in detached and semidetached houses of which owned by public organization share | 0,113 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 480 | buildings | dwellings in townhouses and gallery flats of which owned by private persons share | 0,907 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 481 | buildings | dwellings in townhouses and gallery flats of which owned by community association share | 0,07 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 482 | buildings | dwellings in townhouses and gallery flats of which owned by private organizations share | 0,136 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |

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| 483 | buildings | dwellings in townhouses and gallery flats of which owned by housing cooperative share | 0,003 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 484 | buildings | dwellings in townhouses and gallery flats of which owned by public organization share | 0,007 | 1/100 | Bigalke et al. (2016) | might be double. see census 2011 and microcensus 2018 data! |
| 485 | buildings | energy loss distribution share airing min | 0,1 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 486 | buildings | energy loss distribution share airing max | 0,2 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 487 | buildings | energy loss distribution share windows min | 0,2 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 488 | buildings | energy loss distribution share windows max | 0,25 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 489 | buildings | energy loss distribution share chimney and heating system min | 0,3 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 490 | buildings | energy loss distribution share chimney and heating system max | 0,35 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 491 | buildings | energy loss distribution share floor min | 0,05 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 492 | buildings | energy loss distribution share floor max | 0,1 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 493 | buildings | energy loss distribution share roof min | 0,15 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 494 | buildings | energy loss distribution share roof max | 0,2 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 495 | buildings | energy loss distribution share wall min | 0,2 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 496 | buildings | energy loss distribution share wall max | 0,25 | 1/100 | BINE Informationsdienst / Energiesparen im Haushalt | FIZ Karlsruhe |
| 497 | buildings | energy improvement example single family house potential roof | 0,75 | 1/100 | www.bdew.de ("Infografiken Gebäudetechnik") | |
| 498 | buildings | energy improvement example single family house potential wall | 0,71 | 1/100 | www.bdew.de ("Infografiken Gebäudetechnik") | |
| 499 | buildings | energy improvement example single family house potential floor | 0,59 | 1/100 | www.bdew.de ("Infografiken Gebäudetechnik") | |
| 500 | buildings | energy improvement example single family house potential window glazing | 0,47 | 1/100 | www.bdew.de ("Infografiken Gebäudetechnik") | |
| 501 | buildings | completed construction dwelling houses total amount | 18649 | 1 | destatis-31121 | Anzahl Wohngebäude 2018 |
| 502 | buildings | completed construction dwelling houses cumulated living area+useful area | 32324 | 1000 m2 | destatis-31121 | Nutzfläche in Wohngebäuden 2018 |
| 503 | buildings | completed construction dwelling houses cumulated costs total amount | 5374526 | 1000 EUR | destatis-31121 | Veranschlagte Kosten des Bauwerks Wohngebäude 2018 |
| 504 | buildings | completed construction non-residential buildings total amount | 8768 | 1 | destatis-31121 | Anzahl Nichtwohngebäude 2018 |
| 505 | buildings | completed construction non-residential buildings cumulated useful area+living area | 26220 | 1000 m2 | destatis-31121 | Nutzfläche in Nichtwohngebäuden 2018 |
| 506 | buildings | completed construction non-residential buildings cumulated costs total amount | 7938028 | 1000 EUR | destatis-31121 | Veranschlagte Kosten des Bauwerks Nichtwohngebäude 2018 |
| 507 | buildings | completed construction share of dwelling houses by useful area | 0,552131 | 1/100 | destatis-31121 | |
| 508 | buildings | wage in main construction trade per hour | 21 | EUR | destatis: 1020210201015 / Punkt 13.1 | |
| 509 | buildings | working hours main construction trade per week rounded | 40 | hours | destatis: 1020210201015 / Punkt 13.1 | |
| 510 | buildings | main construction trade workforce total | 871928 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 511 | buildings | main construction trade workforce concerned with construction of buildings total | 276316 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 512 | buildings | main construction trade workforce concerned with construction of roads and railways | 116064 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 513 | buildings | main construction trade workforce concerned with construction of pipes and purification plants | 72106 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 514 | buildings | main construction trade workforce concerned with construction of other civil engineering facilities total | 54352 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 515 | buildings | main construction trade workforce concerned with construction of other civil engineering facilities share watersupply network | 1932 | persons | destatis: 1020210201015 / Punkt 15.1 | |

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| 516 | buildings | main construction trade workforce concerned with demolition works and construction site preparation | 39923 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 517 | buildings | main construction trade workforce concerned with other specialized construction total | 313167 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 518 | buildings | main construction trade workforce concerned with other specialized construction share roofing and carpentry | 170466 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 519 | buildings | main construction trade workforce concerned with other specialized construction share scaffolding | 34160 | persons | destatis: 1020210201015 / Punkt 15.1 | |
| 520 | buildings | main construction trade workforce total | 1 | 1/100 | destatis: 1020210201015 / Punkt 15.1 | |
| 521 | buildings | main construction trade workforce concerned with construction of buildings total share | 0,317 | 1/100 | destatis: 1020210201015 / Punkt 15.1 | |
| 522 | buildings | main construction trade workforce concerned with construction of roads and railways share | 0,133 | 1/100 | destatis: 1020210201015 / Punkt 15.1 | |
| 523 | buildings | main construction trade workforce concerned with construction of pipes and purification plants share | 0,083 | 1/100 | destatis: 1020210201015 / Punkt 15.1 | |
| 524 | buildings | main construction trade workforce concerned with construction of other civil engineering facilities total share | 0,062 | 1/100 | destatis: 1020210201015 / Punkt 15.1 | |
| 525 | buildings | main construction trade workforce concerned with demolition works and construction site preparation share | 0,046 | 1/100 | destatis: 1020210201015 / Punkt 15.1 | |
| 526 | buildings | main construction trade workforce concerned with other specialized construction total share | 0,359 | 1/100 | destatis: 1020210201015 / Punkt 15.1 | |
| 527 | buildings | construction work on existing dwelling houses 2018 in sqm of total area | 5655 | m2 | destatis-53111 | |
| 528 | buildings | upgrade cost roof min | 30 | EUR/m2 | www.energie-fachberater.de | considering the different methods and roof types, mean should be around 70 EUR/m2 |
| 529 | buildings | upgrade cost roof max | 250 | EUR/m2 | www.energie-fachberater.de | |
| 530 | buildings | upgrade cost wall min | 80 | EUR/m2 | www.energie-fachberater.de | |
| 531 | buildings | upgrade cost wall max | 200 | EUR/m2 | www.energie-fachberater.de | |
| 532 | buildings | upgrade cost glazing min | 417 | EUR/m2 | www.energie-fachberater.de | 500 EUR/Stk -> at roughly 1,2sqm for a normal window |
| 533 | buildings | upgrade cost glazing max | 650 | EUR/m2 | www.energie-fachberater.de | 780 EUR/Stk -> at roughly 1,2sqm for a normal window |
| 534 | buildings | upgrade cost floor - basement ceiling insulation min | 15 | EUR/m2 | www.energie-fachberater.de | |
| 535 | buildings | upgrade cost floor - basement ceiling insulation max | 50 | EUR/m2 | www.energie-fachberater.de | |
| 536 | buildings | upgrade cost heating system old to new gas min | 46 | EUR/m2 | www.energie-fachberater.de | Stückpreis min ca. 6400 inkl. Rohr und Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 537 | buildings | upgrade cost heating system old to new gas max | 64 | EUR/m2 | www.energie-fachberater.de | Stückpreis max ca. 9000 inkl. Rohr und Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 538 | buildings | upgrade cost electricity storage per kWh | 1000 | EUR | www.energie-fachberater.de | |
| 539 | buildings | upgrade cost electricity storage for 4p hh min | 43 | EUR/m2 | www.energie-fachberater.de | Stückpreis min ca. 6000 inkl. Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 540 | buildings | upgrade cost electricity storage for 4p hh max | 107 | EUR/m2 | www.energie-fachberater.de | Stückpreis max ca. 15000 inkl. Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 541 | buildings | addon cost solar thermal system complete for 4p hh min | 74 | EUR/m2 | www.energie-fachberater.de | Stückpreis min ca. 10400 inkl. Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 542 | buildings | addon cost solar thermal system complete for 4p hh max | 93 | EUR/m2 | www.energie-fachberater.de | Stückpreis max ca. 13000 inkl. Arbeitskosten. avg Preis auf 140sqm angesetzt |

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| 543 | buildings | addon cost solar pv system without storage for 4p hh min | 37 | EUR/m2 | www.energie-fachberater.de | Stückpreis min ca. 5200 inkl. Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 544 | buildings | addon cost solar pv system without storage for 4p hh max | 62 | EUR/m2 | www.energie-fachberater.de | Stückpreis max ca. 8700 inkl. Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 545 | buildings | addon cost solar pv system with storage for 4p hh min | 57 | EUR/m2 | www.energie-fachberater.de | Stückpreis min ca. 8000 inkl. Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 546 | buildings | addon cost solar pv system with storage for 4p hh max | 134 | EUR/m2 | www.energie-fachberater.de | Stückpreis max ca. 18700 inkl. Arbeitskosten. avg Preis auf 140sqm angesetzt |
| 547 | buildings | addon solar pv avg energy production factor per sqm | 0,11 | kWp/m2 | http://www.inbalance-energy.co.uk/articles/solar_panels_pv_calculator.html and https://www.solaranlagen-portal.com/photovoltaik/leistung | |
| 548 | buildings | addon solar pv fraction of total roof size min | 0,1 | 1/100 | own estimate | |
| 549 | buildings | addon solar pv fraction of total roof size max | 0,3 | 1/100 | own estimate | |
| 550 | buildings | addon solar thermal avg potential share of yearly heat water consumption | 0,6 | 1/100 | www.energie-fachberater.de | |
| 551 | buildings | addon solar thermal avg collector size per 4p hh sqm | 6 | m2 | www.energie-fachberater.de | |
| 552 | buildings | upgrade armortization time roof upgrade | 7 | years | www.energie-fachberater.de | considering armortization of top ceiling is 2-5yrs, pointed roof is 6-16 yrs, flat roof is 5-13yrs |
| 553 | buildings | upgrade armortization time wall upgrade | 11 | years | www.energie-fachberater.de | pre 1978 houses: 4-10yrs with mean 6yrs, 1978-1995 houses: 9-22yrs with mean 15yrs |
| 554 | buildings | upgrade armortization time glazing upgrade | | years | www.energie-fachberater.de | |
| 555 | buildings | upgrade armortization time floor upgrade | 6 | years | www.energie-fachberater.de | |
| 556 | buildings | upgrade armortization time heating system upgrade | | years | www.energie-fachberater.de | |

## Table 1: GHG emissions sector

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 557 | co2 | pellet boiler co2equ emissions | 23 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 558 | co2 | pellet boiler particles emissions | 73 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 559 | co2 | pellet furnace co2equ emissions | 22 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 560 | co2 | pellet furnace particles emissions | 116 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 561 | co2 | woodchips boiler co2equ emissions | 28 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 562 | co2 | woodchips boiler particles emissions | 76 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 563 | co2 | firewood boiler co2equ emissions | 17 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 564 | co2 | firewood boiler particles emissions | 144 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 565 | co2 | firewood furnace co2equ emissions | 26 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 566 | co2 | firewood furnace particles emissions | 382 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 567 | co2 | air heat pump co2equ emissions | 201 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 568 | co2 | air heat pump particles emissions | 20 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 569 | co2 | natural gas boiler co2equ emissions | 247 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |

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|---|---|---|---|---|---|---|
| 570 | co2 | natural gas boiler particles emissions | 6 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 571 | co2 | heating oil co2equ emissions | 318 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 572 | co2 | heating oil particles emissions | 22 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 573 | co2 | district heating co2equ emissions | 311 | g/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 574 | co2 | district heating particles emissions | 73 | mg/kWh | https://www.effizienzhaus-online.de/heizung-energietraeger-und-klimabilanz | |
| 575 | co2 | heating energy demand 120m2 living space pa | 15000 | kWh/a | https://www.polarstern-energie.de/magazin/artikel/heizen-co2-vergleich-von-brennstoffen/ | |
| 576 | co2 | electricity mix co2equ emissions | 474 | g/kWh | https://www.energie-lexikon.info/warmwasser.html | |
| 577 | co2 | heating energy demand constructed 1900-1960 yearly mean | 160 | kWh/(m2*a) | https://www.enbausa.de/heizung/aktuelles/artikel/altbauten-brauchen-weniger-energie-als-angenommen-1056.html | note: claim heating energy consumption per m2/construction year is significantly lower than posted by heizung.de |
| 578 | co2 | heating energy demand constructed 1900-1960 yearly top 10% min | 240 | kWh/(m2*a) | https://www.enbausa.de/heizung/aktuelles/artikel/altbauten-brauchen-weniger-energie-als-angenommen-1056.html | note: claim heating energy consumption per m2/construction year is significantly lower than posted by heizung.de |
| 579 | co2 | heating energy demand constructed until 1977 small multi-family buildings avg min | 140 | kWh/(m2*a) | https://www.enbausa.de/heizung/aktuelles/artikel/altbauten-brauchen-weniger-energie-als-angenommen-1056.html | note: claim heating energy consumption per m2/construction year is significantly lower than posted by heizung.de |
| 580 | co2 | heating energy demand constructed until 1977 small multi-family buildings avg max | 157 | kWh/(m2*a) | https://www.enbausa.de/heizung/aktuelles/artikel/altbauten-brauchen-weniger-energie-als-angenommen-1056.html | note: claim heating energy consumption per m2/construction year is significantly lower than posted by heizung.de |
| 581 | co2 | buildings construction carbon emissions | to complete---------------> | | https://constructech.com/carbon-emissions-in-construction-materials/ | |
| 582 | co2 | CO2 emissions from plastic production (example UK) | to complete---------------> | | https://www.statista.com/statistics/485966/co2-emissions-from-the-manufacture-of-plastic-products-uk/ | |
| 583 | co2 | CEV avg CO2 emissions per km at 4kg CNG/100km | 109 | g/km | https://www.audi.de/de/brand/de/neuwagen/a4/a4-avant-g-tron.html | |
| 584 | co2 | ghg emissions public transport (combined direct emissions) per pkm | 0,053489 | kg/pkm | https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#verkehrsmittelvergleich_personenverkehr and https://www.forschungsinformationssystem.de/servlet/is/345756/ and https://www.mobi-wissen.de/Nachhaltigkeit-und-Umweltschutz/Klimaschutz | 2018 |
| 585 | co2 | ghg emissions public transport (metro, tram, emissions from energy mix) per pkm | 0,058 | kg/pkm | https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#verkehrsmittelvergleich_personenverkehr | 2018 |
| 586 | co2 | ghg emissions public transport (omnibus) per pkm | 0,08 | kg/pkm | https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#verkehrsmittelvergleich_personenverkehr | 2018 |
| 587 | co2 | ghg emissions regional rail (energy mix) per pkm | 0,057 | kg/pkm | https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#verkehrsmittelvergleich_personenverkehr | 2018 |
| 588 | co2 | ghg emissions long distance coach (omnibus) per pkm | 0,029 | kg/pkm | https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#verkehrsmittelvergleich_personenverkehr | 2018 |
| 589 | co2 | ghg emissions rail passenger transport (energy mix) per pkm | 0,032 | kg/pkm | https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#verkehrsmittelvergleich_personenverkehr | 2018 |
| 590 | co2 | ghg emissions rail passenger transport (long distance 100%REN) per pkm | 0 | kg/pkm | https://inside.bahn.de/bahn-umwelt-gruen/ | |
| 591 | co2 | ghg emissions air passenger transport (kerosene) per pkm | 0,23 | kg/pkm | https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#verkehrsmittelvergleich_personenverkehr | 2018 |
| 592 | co2 | CO2 factor direct and indirect emissions upon combustion of 1 liter petrol to kg CO2equ | 2,877 | kg/l | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |

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|---|---|---|---|---|---|---|
| 593 | co2 | CO2 factor direct and indirect emissions upon combustion of 1 liter diesel to kg CO2equ | 3,156 | kg/l | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 594 | co2 | CO2 factor direct and indirect emissions upon combustion of 1 m3 natural gas (CNG) to kg CO2equ | 2,42 | kg/m3 | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 595 | co2 | CO2 factor direct and indirect emissions upon combustion of 1 liter auto gas (LPG) to kg CO2equ | 1,809 | kg/l | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 596 | co2 | CO2 factor direct and indirect emissions upon combustion of 1 kWh petrol to kg CO2equ | 0,33453 | kg/kWh | own estimate | |
| 597 | co2 | CO2 factor direct and indirect emissions upon combustion of 1 kWh diesel to kg CO2equ | 0,31879 | kg/kWh | own estimate | |
| 598 | co2 | CO2 factor direct and indirect emissions upon combustion of 1 kWh natural gas (CNG) to kg CO2equ | 0,24683 | kg/kWh | own estimate | |
| 599 | co2 | CO2 factor direct and indirect emissions upon combustion of 1 kWh auto gas (LPG) to kg CO2equ | 0,26603 | kg/kWh | own estimate | |
| 600 | co2 | CO2 factor gross emissions average from 1 kWh LPG and CNG to kg CO2equ | 0,25643 | kg/kWh | own estimate | |
| 601 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Strom-Mix Deutschland for electricity production | 0,501538 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 602 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Braunkohle for electricity production | 1,059358 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 603 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Steinkohle for electricity production | 0,953341 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 604 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Erdgas for electricity production | 0,427771 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 605 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Öl for electricity production | 0,830026 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 606 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Kernenergie for electricity production | 0,067787 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 607 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Photovoltaik for electricity production | 0,06781 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 608 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Wind_onshore for electricity production | 0,01069 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 609 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Wind_offshore for electricity production | 0,00618 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 610 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Laufwasserkraftwerk for electricity production | 0,0027 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 611 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Speicherwasserkraftwerk for electricity production | 0,02614 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 612 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Pumpspeicherkraftwerk for electricity production | 0,02614 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 613 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Geothermie for electricity production | 0,19992 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 614 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Biogas average for electricity production | 0,292 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 615 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Biomethan average for electricity production | 0,244 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 616 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of liquid biomass for electricity production | 0,174 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 617 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of gas from purification plants for electricity production | 0,131211 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 618 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of landfill gas for electricity production | 0,131108 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 619 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of biogenic portion of waste for electricity production | 0,00475 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 620 | co2 | CO2 factor summary categories gross emissions from 1 kWh of electricity produced from coal and oil | 0,947575 | kg/kWh | own estimate | groups made from above data |

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|---|---|---|---|---|---|---|
| 621 | co2 | CO2 factor summary categories gross emissions from 1 kWh of electricity produced from natural gas | 0,427771 | kg/kWh | own estimate | groups made from above data |
| 622 | co2 | CO2 factor summary categories gross emissions from 1 kWh of electricity produced from nuclear | 0,067787 | kg/kWh | own estimate | groups made from above data |
| 623 | co2 | CO2 factor summary categories gross emissions from 1 kWh of electricity produced from solar PV | 0,06781 | kg/kWh | own estimate | groups made from above data |
| 624 | co2 | CO2 factor summary categories gross emissions from 1 kWh of electricity produced from on and offshore wind | 0,008435 | kg/kWh | own estimate | groups made from above data |
| 625 | co2 | CO2 factor summary categories gross emissions from 1 kWh of electricity produced from flowing and pumped hydropower | 0,018326 | kg/kWh | own estimate | groups made from above data |
| 626 | co2 | CO2 factor summary categories gross emissions from 1 kWh of electricity produced from geothermal | 0,19992 | kg/kWh | own estimate | groups made from above data |
| 627 | co2 | CO2 factor summary categories gross emissions from 1 kWh of electricity produced from waste landfill liquid and hard source biogas | 0,162844 | kg/kWh | own estimate | groups made from above data |
| 628 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Wärme-Mix Deutschland for heating | 0,28218 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 629 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Heizöl for heating | 0,31793 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 630 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Erdgas for heating | 0,24683 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 631 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Steinkohle for heating | 0,40101 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 632 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Braunkohle for heating | 0,42791 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 633 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Fernwärme for heating | 0,3145 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 634 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Stromheizung for heating | 0,60497 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 635 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of Scheitholz Holzpellets Hackschnitzel average for heating | 0,021 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 636 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of solid biomass industry average for heating | 0,022 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 637 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of solid biomass heizkraftwerk average for heating | 0,032 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 638 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of liquid biomass average for heating | 0,099 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 639 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of biogas average for heating | 0,119 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 640 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of biomethane average for heating | 0,113 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 641 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of gas from purification plants for heating | 0,035 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 642 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of ladfill gas for heating | 0,037 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 643 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of biogenic portion of waste for heating | 0,001 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 644 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of solarthermal energy average for heating | 0,023 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 645 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of heat pumps average for heating | 0,195 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 646 | co2 | CO2 factor direct and indirect emissions from using 1 kWh of deep geothermal energy for heating | 0,037 | kg/kWh | https://www.umweltpakt.bayern.de/energie_klima/fachwissen/217/berechnung-co2-emissionen | |
| 647 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from heating oil | 0,31793 | kg/kWh | own estimate | groups made from above data |
| 648 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from natural gas | 0,24683 | kg/kWh | own estimate | groups made from above data |
| 649 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from hard coal and lignite | 0,41446 | kg/kWh | own estimate | groups made from above data |

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|---|---|---|---|---|---|---|
| 650 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from district heating | 0,3145 | kg/kWh | own estimate | groups made from above data |
| 651 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from electricity heating | 0,60497 | kg/kWh | own estimate | groups made from above data |
| 652 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from wood types | 0,021 | kg/kWh | own estimate | groups made from above data |
| 653 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from biomass and biogas non wood | 0,05725 | kg/kWh | own estimate | groups made from above data |
| 654 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from solarthermal | 0,023 | kg/kWh | own estimate | groups made from above data |
| 655 | co2 | CO2 factor summary categories gross emissions from 1 kWh of heat produced from geothermal and heat pumps | 0,116 | kg/kWh | own estimate | groups made from above data |
| 656 | co2 | CO2 emissions from local bus and rail transport in kg CO2equ per passenger km | 0,08 | kg/pkm | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 657 | co2 | CO2 emissions from national bus transport in kg CO2equ per passenger km | 0,03 | kg/pkm | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 658 | co2 | CO2 emissions from national rail transport in kg CO2equ per passenger km | 0,05 | kg/pkm | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 659 | co2 | CO2 emissions from air transport in kg CO2equ per passenger km | 0,27 | kg/pkm | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 660 | co2 | CO2 emissions from cruise ship transport in kg CO2equ per passenger days at sea | 280 | kg/d | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 661 | co2 | CO2 emissions from cruise ship transport in kg CO2equ per passenger days at the port | 190 | kg/d | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 662 | co2 | CO2 emissions from electricity production given the "Energiemix" | 0,401 | kg/kWh | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 663 | co2 | CO2 factor EV emissions from electric charging | 0,508 | kg/kWh | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 664 | co2 | CO2 factor heating with wood in kg CO2 equ | 0,39 | kg/kWh | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 665 | co2 | CO2 factor heating with heating oil in kg CO2 equ | 3,17 | kg/l | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 666 | co2 | CO2 factor heating with natural gas from m3 in kg CO2 equ | 2 | kg/m3 | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 667 | co2 | CO2 factor heating with natural gas from kWh in kg CO2 equ | 0,22 | kg/kWh | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 668 | co2 | CO2 factor heating with hard coal from kg in kg CO2 equ | 2,83 | kg/kg | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 669 | co2 | CO2 factor heating with natural gas from kWh in kg CO2 equ | 0,34 | kg/kWh | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 670 | co2 | CO2 factor heating with lignite briquettes in kg CO2 equ | 2,65 | kg/kg | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 671 | co2 | CO2 factor heating with district heating in kg CO2 equ | 0,12 | kg/kWh | http://www.klimaneutral-handeln.de/php/kompens-berechnen.php | |
| 672 | co2 | co2 starting price 2021 | 25 | EUR/tCO2equ | https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2020/20200520-bundeskabinett-beschliesst-hoeheren-co2-preis.html | |
| 673 | co2 | co2 price linear increase until 2025 | 55 | EUR/tCO2equ | https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2020/20200520-bundeskabinett-beschliesst-hoeheren-co2-preis.html | |
| 674 | co2 | co2 price post 2026 min | 55 | EUR/tCO2equ | https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2020/20200520-bundeskabinett-beschliesst-hoeheren-co2-preis.html | |
| 675 | co2 | co2 price post 2026 max | 65 | EUR/tCO2equ | https://www.bmwi.de/Redaktion/DE/Pressemitteilungen/2020/20200520-bundeskabinett-beschliesst-hoeheren-co2-preis.html | |
| 676 | co2 | EU-28 ghg emissions proxy 2018 | 4.236.27 | kt co2 equivalents | https://www.eea.europa.eu/data-and-maps/data/approximated-estimates-for-greenhouse-gas-emissions-1 | https://www.eea.europa.eu/ds_resolveuid/0b654c6dbdd44ed6a6d07142bd73f275 |
| 677 | co2 | Germany ghg emissions proxy 2018 | 850.381, | kt co2 equivalents | https://www.eea.europa.eu/data-and-maps/data/approximated-estimates-for-greenhouse-gas-emissions-1 | https://www.eea.europa.eu/ds_resolveuid/0b654c6dbdd44ed6a6d07142bd73f275 |
| 678 | co2 | EU-27 without UK ghg emissions proxy 2018 | 3.771.52 | kt co2 equivalents | https://www.eea.europa.eu/data-and-maps/data/approximated-estimates-for-greenhouse-gas-emissions-1 | https://www.eea.europa.eu/ds_resolveuid/0b654c6dbdd44ed6a6d07142bd73f275 |
| 679 | co2 | ghg emissions contribution of Germany to EU-28 | 0,20 | 1/100 | own estimate | |
| 680 | co2 | ghg emissions contribution of Germany to EU-27 | 0,23 | 1/100 | own estimate | |

## Table 1: Economics data

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 681 | economics | GDP (PPP) Germany 2019 | 3435210 | million EUR | https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_gdp&lang=en | |
| 682 | economics | GDP (PPP) EU-28 2019 | 16452065 | million EUR | https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_gdp&lang=en | |
| 683 | economics | GDP (PPP) EU-27 2019 | 13928753 | million EUR | https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_gdp&lang=en | |
| 684 | economics | GDP (PPP) contribution of Germany to EU-28 | 0,208801 | 1/100 | own estimate | |
| 685 | economics | GDP (PPP) contribution of Germany to EU-27 | 0,246627 | 1/100 | own estimate | |

## Table 1: Energy data

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 686 | energy | employment in renewable energy 2016 | 338600 | p | Westermann & Richter (2018) | |
| 687 | energy | employment in renewable energy 2015 estimate | 328600 | p | Westermann & Richter (2018) | |
| 688 | energy | employment in renewable energy 2000 estimate | 110500 | p | Westermann & Richter (2018) | |
| 689 | energy | employment in wind energy 2016 | 160200 | p | Westermann & Richter (2018) | |
| 690 | energy | employment in wind energy 2016 offshore wind | 27000 | p | Westermann & Richter (2018) | |
| 691 | energy | employment in coal mining 2000 | 100000 | p | Westermann & Richter (2018) | |
| 692 | energy | employment in coal mining 2016 | 10000 | p | Westermann & Richter (2018) | |
| 693 | energy | energy hard coal primary consumption total | 1301 | PJ | AGEB annual report 2018 | |
| 694 | energy | energy hard coal primary consumption power plants | 765 | PJ | AGEB annual report 2018 | |
| 695 | energy | energy hard coal primary consumption steel industry | 507 | PJ | AGEB annual report 2018 | |
| 696 | energy | energy hard coal primary consumption heating market | 29 | PJ | AGEB annual report 2018 | |
| 697 | energy | energy hard coal net import volume | 1266 | PJ | AGEB annual report 2018 | |
| 698 | energy | energy hard coal domestic production volume | 76 | PJ | AGEB annual report 2018 | |
| 699 | energy | energy natural gas net import volume | 884 | TWh | AGEB annual report 2018 | total imports less exports and bunkering |
| 700 | energy | energy natural gas domestic production volume | 61 | TWh | AGEB annual report 2018 | |
| 701 | energy | energy natural gas primary consumption total | 945 | TWh | AGEB annual report 2018 | |
| 702 | energy | energy natural gas primary consumption industry | 369 | TWh | AGEB annual report 2018 | |
| 703 | energy | energy natural gas primary consumption electricity production | 110 | TWh | AGEB annual report 2018 | supply to power plants incl. CHP |
| 704 | energy | energy natural gas primary consumption district heating | 67 | TWh | AGEB annual report 2018 | |
| 705 | energy | energy natural gas primary consumption private households | 265 | TWh | AGEB annual report 2018 | |
| 706 | energy | energy natural gas primary consumption trade commerce services | 114 | TWh | AGEB annual report 2018 | |
| 707 | energy | energy natural gas primary consumption transportation | 2 | TWh | AGEB annual report 2018 | |
| 708 | energy | energy natural gas primary consumption selfconsumption losses | 18 | TWh | AGEB annual report 2018 | |
| 709 | energy | energy mineral oil primary consumption total | 103,3 | Mt | AGEB annual report 2018 | in million tons |
| 710 | energy | energy mineral oil primary consumption total | 4443 | PJ | AGEB annual report 2018 | equals: 103,3 Mt co2 equivalets |
| 711 | energy | energy mineral oil primary consumption selfconsumption losses | 5,7 | Mt | AGEB annual report 2018 | in million tons |

| | | | | | | |
|---|---|---|---|---|---|---|
| 712 | energy | energy mineral oil primary consumption gasoline | 18 | Mt | AGEB annual report 2018 | in million tons |
| 713 | energy | energy mineral oil primary consumption diesel fuel | 37,5 | Mt | AGEB annual report 2018 | in million tons |
| 714 | energy | energy mineral oil primary consumption aviation fuels | 10,2 | Mt | AGEB annual report 2018 | in million tons |
| 715 | energy | energy mineral oil primary consumption fuel oil light | 13,3 | Mt | AGEB annual report 2018 | in million tons |
| 716 | energy | energy mineral oil primary consumption fuel oil heavy | 2 | Mt | AGEB annual report 2018 | in million tons |
| 717 | energy | energy mineral oil primary consumption naphtha | 10,8 | Mt | AGEB annual report 2018 | in million tons |
| 718 | energy | energy mineral oil primary consumption liquid gas | 3,6 | Mt | AGEB annual report 2018 | in million tons |
| 719 | energy | energy mineral oil primary consumption lubricants | 1 | Mt | AGEB annual report 2018 | in million tons |
| 720 | energy | energy mineral oil primary consumption other products | 10,2 | Mt | AGEB annual report 2018 | in million tons |
| 721 | energy | energy lignite domestic production | 166,3 | Mt | AGEB annual report 2018 | in million tons |
| 722 | energy | energy lignite domestic production | 1495 | PJ | AGEB annual report 2018 | |
| 723 | energy | energy lignite primary consumption total | 1465 | PJ | AGEB annual report 2018 | |
| 724 | energy | energy gross electricity production lignite | 114 | TWh | ageb-strerz2019_18122019.pdf | |
| 725 | energy | energy gross electricity production nuclear energy | 75,2 | TWh | ageb-strerz2019_18122019.pdf | |
| 726 | energy | energy gross electricity production hard coal | 56,9 | TWh | ageb-strerz2019_18122019.pdf | |
| 727 | energy | energy gross electricity production natural gas | 91,3 | TWh | ageb-strerz2019_18122019.pdf | |
| 728 | energy | energy gross electricity production mineral oil | 5,2 | TWh | ageb-strerz2019_18122019.pdf | |
| 729 | energy | energy gross electricity production renewables total | 242,6 | TWh | ageb-strerz2019_18122019.pdf | |
| 730 | energy | energy gross electricity production renewables wind onshore | 101,8 | TWh | ageb-strerz2019_18122019.pdf | |
| 731 | energy | energy gross electricity production renewables wind offshore | 24,6 | TWh | ageb-strerz2019_18122019.pdf | |
| 732 | energy | energy gross electricity production renewables hydropower | 18,8 | TWh | ageb-strerz2019_18122019.pdf | |
| 733 | energy | energy gross electricity production renewables biomass | 44,8 | TWh | ageb-strerz2019_18122019.pdf | |
| 734 | energy | energy gross electricity production renewables photovoltaik | 46,7 | TWh | ageb-strerz2019_18122019.pdf | |
| 735 | energy | energy gross electricity production renewables household waste | 5,7 | TWh | ageb-strerz2019_18122019.pdf | |
| 736 | energy | energy gross electricity production renewables geothermics | 0,2 | TWh | ageb-strerz2019_18122019.pdf | |
| 737 | energy | energy gross electricity production other total | 26,3 | TWh | ageb-strerz2019_18122019.pdf | |
| 738 | energy | energy gross electricity production other pumped hydro storage | 5,9 | TWh | ageb-strerz2019_18122019.pdf | |
| 739 | energy | energy gross electricity production other household waste | 6 | TWh | ageb-strerz2019_18122019.pdf | |
| 740 | energy | energy gross electricity production other industrial waste | 0,8 | TWh | ageb-strerz2019_18122019.pdf | |
| 741 | energy | energy gross electricity production total | 611,5 | TWh | ageb-strerz2019_18122019.pdf | |
| 742 | energy | energy gross electricity production net imports | -36,6 | TWh | ageb-strerz2019_18122019.pdf | |
| 743 | energy | energy gross electricity production selfconsumption losses | 33,5 | TWh | AGEB annual report 2018 | |
| 744 | energy | energy gross electricity production selfconsumption losses share | 5,1 | 1/100 | AGEB annual report 2018 | |
| 745 | energy | energy net domestic electricity volume grid losses | 27 | TWh | AGEB annual report 2018 | |
| 746 | energy | energy net electricity consumption total | 526 | TWh | AGEB annual report 2018 | |
| 747 | energy | energy net electricity consumption mining manufacturing industries | 247,5 | TWh | AGEB annual report 2018 | |

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|---|---|---|---|---|---|---|
| 748 | energy | energy net electricity consumption households | 127,2 | TWh | AGEB annual report 2018 | |
| 749 | energy | energy net electricity consumption trade commerce services public institutions | 140 | TWh | AGEB annual report 2018 | |
| 750 | energy | energy net electricity consumption transportation | 11,3 | TWh | AGEB annual report 2018 | |
| 751 | energy | energy renewable energy sources structure waste | 6,6 | 1/100 | AGEB annual report 2018 | also see countrydata |
| 752 | energy | energy renewable energy sources structure biomass | 53,6 | 1/100 | AGEB annual report 2018 | also see countrydata |
| 753 | energy | energy renewable energy sources structure geothermal | 3,3 | 1/100 | AGEB annual report 2018 | also see countrydata |
| 754 | energy | energy renewable energy sources structure solar all | 11 | 1/100 | AGEB annual report 2018 | also see countrydata |
| 755 | energy | energy renewable energy sources structure wind all | 22,2 | 1/100 | AGEB annual report 2018 | also see countrydata |
| 756 | energy | energy renewable energy sources structure hydropower | 3,3 | 1/100 | AGEB annual report 2018 | also see countrydata |
| 757 | energy | biogas (1m3) equals liters of gasfuel | 0,6 | l/m3 | https://www.bio-power.ch/Fachwissen/Wieviel-Energie-steckt-im-BioabfallIJ/PiKne/ | |
| 758 | energy | biogas (1m3) equals liters of heating oil min | 0,6 | l/m3 | https://www.bio-power.ch/Fachwissen/Wieviel-Energie-steckt-im-BioabfallIJ/PiKne/ | |
| 759 | energy | biogas (1m3) equals liters of heating oil max | 0,65 | l/m3 | https://www.bio-power.ch/Fachwissen/Wieviel-Energie-steckt-im-BioabfallIJ/PiKne/ | |
| 760 | energy | biogas energy content | 5,8 | kWh/m3 | https://www.bio-power.ch/Fachwissen/Wieviel-Energie-steckt-im-BioabfallIJ/PiKne/ | |
| 761 | energy | biogas per ton of liquid manure from cattle and pigs | 20 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 762 | energy | biogas from liquid manure from cattle and pigs CO2 content | 14 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 763 | energy | biogas per ton of fruit pomace | 130 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 764 | energy | biogas from fruit pomace CO2 content | 91 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 765 | energy | biogas per ton of vegetable waste | 55 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 766 | energy | biogas from vegetable waste CO2 content | 38 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 767 | energy | biogas per ton of grass silage | 170 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 768 | energy | biogas from grass silage CO2 content | 119 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 769 | energy | biogas per ton of straw from maize and barley | 310 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 770 | energy | biogas from straw from maize and barley CO2 content | 217 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 771 | energy | biogas per ton of organic household waste | 100 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 772 | energy | biogas from organic household waste CO2 content | 70 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 773 | energy | biogas per ton of fresh pure grass clippings | 80 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 774 | energy | biogas from fresh pure grass clippings CO2 content | 77 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 775 | energy | biogas per ton of food waste | 150 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 776 | energy | biogas from food waste CO2 content | 105 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 777 | energy | biogas per ton of old bread | 480 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 778 | energy | biogas from old bread CO2 content | 336 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 779 | energy | biogas per ton of whey | 40 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 780 | energy | biogas from whey CO2 content | 28 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 781 | energy | biogas per ton of cheese waste | 670 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 782 | energy | biogas from cheese waste CO2 content | 469 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 783 | energy | biogas per ton of beer rape | 75 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |

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|---|---|---|---|---|---|
| 784 | energy | biogas from beer rape CO2 content | 60 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 785 | energy | biogas per ton of baking waste | 650 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 786 | energy | biogas from baking waste CO2 content | 455 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 787 | energy | biogas per ton of material from grease seperator drained | 390 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 788 | energy | biogas from material from grease seperator drained CO2 content | 273 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 789 | energy | biogas per ton of old deep-frying fat | 870 | m3/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 790 | energy | biogas from old deep-frying fat CO2 content | 609 | kg/t | https://www.bio-power.ch/files/4GQ89DX/biogasertrag_und_co2_anteil.pdf | |
| 791 | energy | solar energy technical potential on buildings (all types but only considering areas with 500kWh/(m2a) solar exposure) | 800 | GWp | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 792 | energy | solar energy feasible potential on buildings (all types but only considering areas with 500kWh/(m2a) solar exposure) fraction | 0,333 | 1/100 | own estimate | |
| 793 | energy | solar energy housing buildings fraction of all building types | 0,333 | 1/100 | own estimate | |
| 794 | energy | solar energy feasible potential on housing buildings estimate capacity | 88,7112 | GWp | own estimate | |
| 795 | energy | solar energy feasible potential on housing buildings estimate output energy | 79,13039 | TWh/a | own estimate | |
| 796 | energy | upgrade solar pv potential on housing buildings in sqm conversion | 52753593 | m2 | own estimate | |
| 797 | energy | upgrade solar pv expected full load hours per year | 892 | h/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 798 | energy | upgrade solar pv avg yearly yield per kWp | 950 | kWh/kWp | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 799 | energy | solar pv energy avg yearly output per sqm | 104,5 | kWh/m2 | own estimate | |
| 800 | energy | solar pv efficiency over year incl. inverter | 0,833 | 1/100 | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 801 | energy | solar pv energy output per sqm 2020 | 150 | kWh/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 802 | energy | solar pv estimated lifetime | 30 | a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 803 | energy | CO2 equivalents / kWh from solar PV over lifetime | 67 | g/kWh | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 804 | energy | CO2 equivalents / kWh from German electricity mix 2018 | 474 | g/kWh | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 805 | energy | electricity consumer price 2019 avg | 30,22 | ct/kWh | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 806 | energy | CO2 certificate price 2015-2019 min | 7,5 | EUR/tCO2equ | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 807 | energy | CO2 certificate price 2015-2019 max | 27,5 | EUR/tCO2equ | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 808 | energy | CO2 certificate price 2019 last | 22,5 | EUR/tCO2equ | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 809 | energy | GHG estimated real costs (CO2 equ) | 180 | EUR/tCO2equ | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 810 | energy | EEG electricity supply fixed rate payment until end 2020 | 9,87 | ct/kWh | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | vereinfacht |
| 811 | energy | solar pv yearly required installation rate to reach 400 GWp by 2050 | 12 | GWp/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 812 | energy | solar pv yearly required installation rate to reach 400 GWp by 2050 including replacing 30yr old units | 13 | GWp/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 813 | energy | solar pv yearly required installation rate to reach 65% REN by 2030 (Koalitionsvertrag2018) min | 5 | GWp/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 814 | energy | solar pv yearly required installation rate to reach 65% REN by 2030 (Koalitionsvertrag2018) max | 10 | GWp/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 815 | energy | solar pv yearly required installation rate to reach 95GWp REN by 2030 (Klimaschutzprogramm2019) min | 4,5 | GWp/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |

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|---|---|---|---|---|---|
| 816 | energy | solar pv yearly average installation rate 2013-2018 | 1,8 | GWp/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 817 | energy | solar pv installation rate 2019 | 3,9 | GWp/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 818 | energy | solar pv yearly required installation rate to reach 400 GWp by 2050 in energy output | 8,916432 | TWh/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 819 | energy | solar pv yearly required installation rate to reach 400 GWp by 2050 including replacing 30yr old units energy output | 9,659468 | TWh/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 820 | energy | solar pv yearly required installation rate to reach 65% REN by 2030 (Koalitionsvertrag2018) min energy output | 3,71518 | TWh/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 821 | energy | solar pv yearly required installation rate to reach 65% REN by 2030 (Koalitionsvertrag2018) max energy output | 7,43036 | TWh/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 822 | energy | solar pv yearly required installation rate to reach 95GWp REN by 2030 (Klimaschutzprogramm2019) min energy output | 3,343662 | TWh/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 823 | energy | solar pv yearly average installation rate 2013-2018 energy output | 1,337464 | TWh/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 824 | energy | solar pv installation rate 2019 energy output | 2,897840 | TWh/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 825 | energy | CEV energy content CNG per kg | 13,3 | kWh/kg | https://www.fluessiggas1.de/fluessiggas_umrechnung_kwh_m3_liter_kg/ |
| 826 | energy | energy consumption public transport total avg per pkm | 0,316796 | kWh/pkm | https://www.forschungsinformationssystem.de/servlet/is/343659/ and https://www.sileo-ebus.com/ |
| 827 | energy | energy consumption public transport bus avg per pkm | 0,338888 | kWh/pkm | https://www.forschungsinformationssystem.de/servlet/is/343659/ |
| 828 | energy | energy consumption public transport rail avg per pkm | 0,272222 | kWh/pkm | https://www.forschungsinformationssystem.de/servlet/is/343659/ |
| 829 | energy | energy consumption rail avg per pkm | 0,105555 | kWh/pkm | https://www.forschungsinformationssystem.de/servlet/is/342234/ and https://www.forschungsinformationssystem.de/servlet/is/343659/ |
| 830 | energy | energy consumption air passenger transport total avg per pkm | 0,520504 | kWh/pkm | https://www.forschungsinformationssystem.de/servlet/is/342234/ and https://www.forschungsinformationssystem.de/servlet/is/343659/ |
| 831 | energy | energy consumption air passenger transport international avg per pkm | 0,4785 | kWh/pkm | https://www.forschungsinformationssystem.de/servlet/is/342234/ and https://www.forschungsinformationssystem.de/servlet/is/343659/ |
| 832 | energy | energy consumption air passenger transport inland avg per pkm | 0,7656 | kWh/pkm | https://www.forschungsinformationssystem.de/servlet/is/342234/ and https://www.forschungsinformationssystem.de/servlet/is/343659/ |
| 833 | energy | energy consumption bycicle (ebike) avg per pkm | 0,007 | kWh/pkm | https://www.eradhafen.de/2011/02/wie-viel-energie-verbraucht-ein-elektrofahrrad-was-fur-eine-co2-bilanz-hat-das-fahren/ |
| 834 | energy | energy content LPG in calorific value per m3 | 28,14 | kWh | https://www.fluessiggas1.de/fluessiggas_umrechnung_kwh_m3_liter_kg/ |
| 835 | energy | energy content LPG in calorific value kWh/l | 7,17 | kWh/l | https://www.fluessiggas1.de/fluessiggas_umrechnung_kwh_m3_liter_kg/ |
| 836 | energy | energy content of 1 liter petrol fuel | 8,6 | kWh/l | https://www.erdgas.info/erdgas-mobil/erdgas-als-kraftstoff/reichweite-von-gas-autos/ |
| 837 | energy | energy content of 1 liter diesel fuel | 9,9 | kWh/l | https://www.erdgas.info/erdgas-mobil/erdgas-als-kraftstoff/reichweite-von-gas-autos/ |
| 838 | energy | energy content of 1 kg CNG fuel | 13,3 | kWh/kg | https://www.erdgas.info/erdgas-mobil/erdgas-als-kraftstoff/reichweite-von-gas-autos/ |
| 839 | energy | energy content of 1 liter LPG fuel | 6,8 | kWh/l | https://www.erdgas.info/erdgas-mobil/erdgas-als-kraftstoff/reichweite-von-gas-autos/ |
| 840 | energy | energy content of 1 liter kerosene Jet A-1 | 9,57 | kWh/l | https://de.wikipedia.org/wiki/Kerosin |
| 841 | energy | solar pv installation share of total capacity on prive roof tops max | 0,15 | 1/100 | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 842 | energy | solar pv installed capacity 2019 | 49 | GWp | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 843 | energy | solar pv energy output 2019 | 46,7 | TWh | BSW-Solar |
| 844 | energy | solar pv installed systems 2019 | 1700000 | 1 | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |
| 845 | energy | solar pv installed capacity on private roof tops max estimate | 7,35 | GWp | own estimate |
| 846 | energy | energy consumption private household share heating energy total | 0,61 | 1/100 | https://de.wikipedia.org/wiki/Thermische_Solaranlage |
| 847 | energy | energy consumption private household share heating energy for warm drinkable water | 0,08 | 1/100 | https://de.wikipedia.org/wiki/Thermische_Solaranlage |
| 848 | energy | energy consumption private household share heating energy for heating water | 0,53 | 1/100 | https://de.wikipedia.org/wiki/Thermische_Solaranlage |

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|---|---|---|---|---|---|---|
| 849 | energy | energy consumption private household share motor vehicles | 0,31 | 1/100 | https://de.wikipedia.org/wiki/Thermische_Solaranlage | |
| 850 | energy | energy consumption private household share electricity | 0,08 | 1/100 | https://de.wikipedia.org/wiki/Thermische_Solaranlage | |
| 851 | energy | energy consumption private household share heating energy total 2018 | 0,835 | 1/100 | https://www.umweltbundesamt.de/daten/private-haushalte-konsum/wohnen/energieverbrauch-privater-haushalte#hochster-anteil-am-energieverbrauch-zum-heizen | |
| 852 | energy | energy consumption private household share heating energy for warm drinkable water 2018 | 0,159 | 1/100 | https://www.umweltbundesamt.de/daten/private-haushalte-konsum/wohnen/energieverbrauch-privater-haushalte#hochster-anteil-am-energieverbrauch-zum-heizen | |
| 853 | energy | energy consumption private household share heating energy for heating water 2018 | 0,676 | 1/100 | https://www.umweltbundesamt.de/daten/private-haushalte-konsum/wohnen/energieverbrauch-privater-haushalte#hochster-anteil-am-energieverbrauch-zum-heizen | |
| 854 | energy | energy consumption private household share electricity 2018 | 0,165 | 1/100 | https://www.umweltbundesamt.de/daten/private-haushalte-konsum/wohnen/energieverbrauch-privater-haushalte#hochster-anteil-am-energieverbrauch-zum-heizen | |
| 855 | energy | energy for warm water heating of total heating demand fraction | 0,131147 | 1/100 | own estimate | |
| 856 | energy | energy for household heating of total heating demand fraction | 0,868852 | 1/100 | own estimate | |
| 857 | energy | energy savings potential of total heating energy of solar thermal for warm water heating | 0,078688 | 1/100 | own estimate | |
| 858 | energy | solar thermal availability over year min | 0,6 | 1/100 | own estimate | |
| 859 | energy | solar thermal availability over year max | 0,8 | 1/100 | own estimate | |
| 860 | energy | solar thermal availability not useful during fraction of the year | 0,2 | 1/100 | own estimate | 20% summertime no heating need |
| 861 | energy | solar thermal coverage intensity during available time | 0,8 | 1/100 | own estimate | |
| 862 | energy | solar thermal effective use of energy produced fraction min | 0,32 | 1/100 | own estimate | |
| 863 | energy | solar thermal effective use of energy produced fraction max | 0,48 | 1/100 | own estimate | |
| 864 | energy | solar thermal effective household heating energy use avg of total production capacity fraction | 0,4 | 1/100 | own estimate | most heating need in winter, solar capacity covers 80-60% =70% of the year, 20% of which when no heating need =40-60%. for these assuming an available coverage of 70-80% solar capacity =>30-50% effective use of total available solar thermal energy for heating |
| 865 | energy | energy savings potential of total heating energy of solar thermal for household heating | 0,347540 | 1/100 | own estimate | |
| 866 | energy | total average energy savings potential of total heating energy from solar thermal capacity | 0,213114 | 1/100 | own estimate | assuming 50/50 installed systems for warm water and household heating |
| 867 | energy | solar thermal avg existing energy reduction potential of total heating energy demand min | 0,04 | 1/100 | https://de.wikipedia.org/wiki/Thermische_Solaranlage | |
| 868 | energy | solar thermal avg possible energy reduction potential of total heating energy demand max | 0,4 | 1/100 | https://de.wikipedia.org/wiki/Thermische_Solaranlage | |
| 869 | energy | solar thermal energy contribution 2013 | 6,8 | TWh | https://www.solaranlagen-portal.com/solar/solarenergie/waerme | |
| 870 | energy | solar thermal avg energy yield per sqm installed estimate Germany | 566,72 | kWh/(m2*a) | https://www.paradigma.de/produkte/solarheizung/solarkollektoren/ | |
| 871 | energy | solar thermal avg effectively useable energy per sqm installed for heating systems estimate Germany | 350,4 | kWh/(m2*a) | http://hahn-solar.com/solarthermie/ | |
| 872 | energy | solar thermal heating system avg collector size min | 8 | m2 | https://www.solaranlagen-portal.com/solarthermie | |
| 873 | energy | solar thermal heating system avg collector size max | 15 | m2 | https://www.solaranlagen-portal.com/solarthermie | |
| 874 | energy | solar thermal heating system avg price min | 7106 | EUR | https://www.solaranlagen-portal.com/solarthermie | |

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|---|---|---|---|---|---|---|
| 875 | energy | solar thermal heating system avg price max | 9133 | EUR | https://www.solaranlagen-portal.com/solarthermie | |
| 876 | energy | solar thermal heating system gov support min | 2000 | EUR | https://www.solaranlagen-portal.com/solarthermie | |
| 877 | energy | solar thermal use water heating avg collector size min | 4 | m2 | https://www.solaranlagen-portal.com/solarthermie | |
| 878 | energy | solar thermal use water heating avg collector size max | 6 | m2 | https://www.solaranlagen-portal.com/solarthermie | |
| 879 | energy | solar thermal use water heating avg price min | 3245 | EUR | https://www.solaranlagen-portal.com/solarthermie | |
| 880 | energy | solar thermal use water heating avg price max | 4795 | EUR | https://www.solaranlagen-portal.com/solarthermie | |
| 881 | energy | solar thermal use water heating gov support min | 500 | EUR | https://www.solaranlagen-portal.com/solarthermie | |
| 882 | energy | solar thermal avg useable energy from global radiation | 0,5 | 1/100 | https://www.solarthermie.net/wissen/globalstrahlung-deutschland | |
| 883 | energy | solar thermal avg useable energy from global radiation | 350,4 | kWh/ | http://hahn-solar.com/solarthermie/ | |
| 884 | energy | solar thermal use water heating effective energy saving factor | 0,95 | 1/100 | https://www.solarthermie.net/wissen/globalstrahlung-deutschland | max production is in summer when less warm water is needed |
| 885 | energy | solar thermal heating system effective energy saving factor | 0,7 | 1/100 | https://www.solarthermie.net/wissen/globalstrahlung-deutschland | max production is in summer when heating is not needed, only warm water use |
| 886 | energy | electricity price 2019 | 0,3045 | EUR/kWh | https://strom-report.de/strompreise/strompreisentwicklung/ | |
| 887 | energy | electricity price composition market price | 0,0706 | EUR/kWh | https://strom-report.de/strompreise/strompreis-zusammensetzung/ | |
| 888 | energy | electricity price composition taxes | 0,16 | EUR/kWh | https://strom-report.de/strompreise/strompreis-zusammensetzung/ | |
| 889 | energy | electricity price composition grid and operator costs | 0,0739 | EUR/kWh | https://strom-report.de/strompreise/strompreis-zusammensetzung/ | |
| 890 | energy | solar pv characteristic yearly operating hours | 8760 | h/a | https://de.wikipedia.org/wiki/Solarpark_Lieberose | |
| 891 | energy | coal characteristic yearly full load operating hours | 7500 | h/a | https://de.wikipedia.org/wiki/Kohlekraftwerk_Moorburg | |
| 892 | energy | hydro power run-of-the-river characteristic yearly full load operating hours | 8760 | h/a | https://de.wikipedia.org/wiki/Staustufe_D%C3%B6rverden | |
| 893 | energy | waste incineration characteristic yearly full load operating hours | 8000 | h/a | https://de.wikipedia.org/wiki/M%C3%BCllheizkraftwerk_Kempten | |
| 894 | energy | policy driven yearly reduction of energy production from nuclear | -37,55 | TWh/a | own estimate | |
| 895 | energy | policy driven yearly reduction of energy production from nuclear deadline | 2022 | a | https://www.bundesregierung.de/breg-de/suche/bundesregierung-beschliesst-ausstieg-aus-der-kernkraft-bis-2022-457246 | |
| 896 | energy | policy driven yearly reduction of energy production from coal | -10,889 | TWh/a | own estimate | |
| 897 | energy | policy driven yearly reduction of energy production from coal deadline | 2038 | a | https://www.faz.net/aktuell/wirtschaft/klima-energie-und-umwelt/kohleausstieg-soll-naechste-woche-beschlossen-werden-16830633.html#void | expected |
| 898 | energy | electricity supply growth rate 10yr avg | -0,0006 | 1/100 | AGEB_ausdruck_strerz_abgabe_20200217.pdf | |
| 899 | energy | Wind-offshore capacity 2018 | 6,6 | GWp | https://www.windguard.com/publications-wind-energy-statistics.html | |
| 900 | energy | Wind-offshore capacity expected 2020 | 7,7 | GWp | https://www.windguard.com/publications-wind-energy-statistics.html | |
| 901 | energy | Wind-offshore total capacity expected 2025 | 10 | GWp | https://www.windguard.com/publications-wind-energy-statistics.html | |
| 902 | energy | Wind-offshore total capacity expected 2030 | 15 | GWp | https://www.windguard.com/publications-wind-energy-statistics.html | |
| 903 | energy | Wind-offshore total capacity policy target 2030 | 20 | GWp | https://www.bundesrat.de/SharedDocs/TO/992/erl/31.pdf?__blob=publicationFile&v=1 | |
| 904 | energy | Wind-offshore total capacity policy target 2035 | 30 | GWp | https://www.bundesrat.de/bv.html?id=0212-20 | |
| 905 | energy | Wind-offshore total capacity policy target 2040 | 40 | GWp | https://www.bundesrat.de/SharedDocs/TO/992/erl/31.pdf?__blob=publicationFile&v=1 | |
| 906 | energy | Wind-offshore electricity output 2018 | 19,3 | TWh | https://www.windguard.com/publications-wind-energy-statistics.html and https://de.wikipedia.org/wiki/Offshore-Windpark#Deutschland | |
| 907 | energy | Wind-offshore estimated load factor | 0,333 | 1/100 | own estimate | |
| 908 | energy | Wind-offshore electricity output estimate 2020 | 22,52 | TWh/a | own estimate | |

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|---|---|---|---|---|---|
| 909 | energy | Wind-offshore total capacity expected 2025 | 29,24 | TWh/a | own estimate |
| 910 | energy | Wind-offshore total capacity expected 2030 | 43,86 | TWh/a | own estimate |
| 911 | energy | Wind-offshore total capacity policy target 2030 | 58,48 | TWh/a | own estimate |
| 912 | energy | Wind-offshore total capacity policy target 2040 | 116,97 | TWh/a | own estimate |
| 913 | energy | Wind-offshore capacity to be built until 2040 | 87,73 | TWh/a | own estimate |
| 914 | energy | Wind-offshore capacity to be installed per year until 2040 | 5,848666 | TWh/a | own estimate |
| 915 | energy | Wind-onshore capacity 2018 | 52,9 | GWp | https://www.windguard.com/publications-wind-energy-statistics.html and https://de.wikipedia.org/wiki/Offshore-Windpark#Deutschland |
| 916 | energy | Wind-onshore capacity 2006 | 20 | GWp | https://www.windguard.com/publications-wind-energy-statistics.html and https://de.wikipedia.org/wiki/Offshore-Windpark#Deutschland |
| 917 | energy | Wind-onshore capacity growth estimate p.a. | 0,13 | 1/100 | own estimate |
| 918 | energy | Wind-onshore electricity output 2018 | 89,5 | TWh | https://www.windguard.com/publications-wind-energy-statistics.html and https://de.wikipedia.org/wiki/Offshore-Windpark#Deutschland |
| 919 | energy | Wind-onshore estimated load factor | 0,193136 | 1/100 | https://www.windguard.com/publications-wind-energy-statistics.html and https://de.wikipedia.org/wiki/Offshore-Windpark#Deutschland |
| 920 | energy | Wind-onshore capacity estimate 2020 | 114,2825 | TWh | own estimate |
| 921 | energy | Wind-offshore lifetime estimate | 20 | a | https://www.topagrar.com/energie/news/windkraft-nach-20-jahren-laufzeit-ist-noch-lange-nicht-schluss-9372151.html |
| 922 | energy | Wind-onshore lifetime estimate | 20 | a | https://www.topagrar.com/energie/news/windkraft-nach-20-jahren-laufzeit-ist-noch-lange-nicht-schluss-9372151.html |

## Table 1: Household data

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 923 | households | electricity consumption 1 person hh yearly avg min | 1000 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 924 | households | electricity consumption 1 person hh yearly avg max | 2000 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 925 | households | electricity consumption 2 person hh yearly avg min | 1500 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 926 | households | electricity consumption 2 person hh yearly avg max | 3000 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 927 | households | electricity consumption 3 person hh yearly avg min | 2000 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 928 | households | electricity consumption 3 person hh yearly avg max | 3500 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 929 | households | electricity consumption 4 person hh yearly avg min | 3000 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 930 | households | electricity consumption 4 person hh yearly avg max | 4500 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | |
| 931 | households | electricity consumption 5 person hh yearly avg min | 4000 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | own estimate |
| 932 | households | electricity consumption 5 person hh yearly avg max | 5500 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | own estimate |
| 933 | households | electricity consumption 6 or more person hh yearly avg min | 4500 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | own estimate |
| 934 | households | electricity consumption 6 or more person hh yearly avg max | 10000 | kWh/a | https://heizung.de/heizung/tipps/der-durchschnittliche-energiebedarf-im-haus/ | own estimate |
| 935 | households | energy final consumption in buildings residential space heating | 462 | TWh | Westermann & Richter (2018) | |
| 936 | households | energy final consumption in buildings residential hot water | 96 | TWh | Westermann & Richter (2018) | |
| 937 | households | energy final consumption in buildings residential lighting | 10 | TWh | Westermann & Richter (2018) | |
| 938 | households | energy final consumption in buildings residential air conditioning | 1 | TWh | Westermann & Richter (2018) | |
| 939 | households | energy final consumption in buildings residential space heating share | 0,811950 | 1/100 | Westermann & Richter (2018) | |
| 940 | households | energy final consumption in buildings residential hot water share | 0,168717 | 1/100 | Westermann & Richter (2018) | |

| | | | | | |
|---|---|---|---|---|---|
| 941 | households | energy final consumption in buildings residential lighting share | 0,017574 | 1/100 | Westermann & Richter (2018) |
| 942 | households | energy final consumption in buildings residential air conditioning share | 0,001757 | 1/100 | Westermann & Richter (2018) |
| 943 | households | energy final consumption in buildings non residential space heating | 245 | TWh | Westermann & Richter (2018) |
| 944 | households | energy final consumption in buildings non residential hot water | 23 | TWh | Westermann & Richter (2018) |
| 945 | households | energy final consumption in buildings non residential lighting | 62 | TWh | Westermann & Richter (2018) |
| 946 | households | energy final consumption in buildings non residential air conditioning | 9 | TWh | Westermann & Richter (2018) |
| 947 | households | energy final consumption in buildings non residential space heating share | 0,722713 | 1/100 | Westermann & Richter (2018) |
| 948 | households | energy final consumption in buildings non residential hot water share | 0,067846 | 1/100 | Westermann & Richter (2018) |
| 949 | households | energy final consumption in buildings non residential lighting share | 0,182890 | 1/100 | Westermann & Richter (2018) |
| 950 | households | energy final consumption in buildings non residential air conditioning share | 0,026548 | 1/100 | Westermann & Richter (2018) |
| 951 | households | energy final consumption by sector private households | 665 | TWh | Westermann & Richter (2018) |
| 952 | households | energy final consumption by sector trade commerce services | 411 | TWh | Westermann & Richter (2018) |
| 953 | households | energy final consumption by sector transport | 749 | TWh | Westermann & Richter (2018) |
| 954 | households | energy final consumption by sector industry | 717 | TWh | Westermann & Richter (2018) |
| 955 | households | energy final consumption total | 2542 | TWh | Westermann & Richter (2018) |
| 956 | households | energy final consumption by energy source electricity total | 0,21 | 1/100 | Westermann & Richter (2018) |
| 957 | households | energy final consumption by energy source electricity from coal | 0,09 | 1/100 | Westermann & Richter (2018) |
| 958 | households | energy final consumption by energy source electricity from renewables | 0,06 | 1/100 | Westermann & Richter (2018) |
| 959 | households | energy final consumption by energy source electricity from nuclear | 0,03 | 1/100 | Westermann & Richter (2018) |
| 960 | households | energy final consumption by energy source electricity from gas | 0,02 | 1/100 | Westermann & Richter (2018) |
| 961 | households | energy final consumption by energy source electricity from oil | 0,002 | 1/100 | Westermann & Richter (2018) |
| 962 | households | energy final consumption by energy source electricity from others | 0,01 | 1/100 | Westermann & Richter (2018) |
| 963 | households | energy final consumption by energy source gas total | 0,26 | 1/100 | Westermann & Richter (2018) |
| 964 | households | energy final consumption by energy source district heating total | 0,04 | 1/100 | Westermann & Richter (2018) |
| 965 | households | energy final consumption by energy source oil incl fuels total | 0,07 | 1/100 | Westermann & Richter (2018) |
| 966 | households | energy final consumption by energy source coal total | 0,05 | 1/100 | Westermann & Richter (2018) |
| 967 | households | energy final consumption by energy source fuel total | 0,29 | 1/100 | Westermann & Richter (2018) |
| 968 | households | energy final consumption by energy source renewables total | 0,07 | 1/100 | Westermann & Richter (2018) |
| 969 | households | energy final consumption by energy source other total | 0,01 | 1/100 | Westermann & Richter (2018) |
| 970 | households | final energy consumption by all private households combined by area of use space heating | 464 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |
| 971 | households | final energy consumption by all private households combined by area of use warm water | 103 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |
| 972 | households | final energy consumption by all private households combined by area of use other process heat | 40 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |
| 973 | households | final energy consumption by all private households combined by area of use climate cooling | 1 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |
| 974 | households | final energy consumption by all private households combined by area of use other process cooling | 29 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |
| 975 | households | final energy consumption by all private households combined by area of use mechanical energy | 6 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| 976 | households | final energy consumption by all private households combined by area of use information and communication technology | 22 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |  |
| 977 | households | final energy consumption by all private households combined by area of use lighting | 10 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |  |
| 978 | households | final energy consumption by all private households combined by area of use total | 675 | TWh | ageb_anteile-anwendungsbereiche-am-eev-ph_2019-10-10.xlsx |  |
| 979 | households | final energy consumption by all private households combined by energy source lignite and hard coal | 6 | TWh | ageb_entwicklung-eev-ph_2019-10-10.xlsx |  |
| 980 | households | final energy consumption by all private households combined by energy source mineral oil | 132 | TWh | ageb_entwicklung-eev-ph_2019-10-10.xlsx |  |
| 981 | households | final energy consumption by all private households combined by energy source gas | 247 | TWh | ageb_entwicklung-eev-ph_2019-10-10.xlsx |  |
| 982 | households | final energy consumption by all private households combined by energy source electricity incl REN | 128 | TWh | ageb_entwicklung-eev-ph_2019-10-10.xlsx |  |
| 983 | households | final energy consumption by all private households combined by energy source district heating incl REN | 52 | TWh | ageb_entwicklung-eev-ph_2019-10-10.xlsx |  |
| 984 | households | final energy consumption by all private households combined by energy source renewable heat from biomass waste solarthermal and envrironmental heat | 86 | TWh | ageb_entwicklung-eev-ph_2019-10-10.xlsx |  |
| 985 | households | final energy consumption by all private households combined by energy source other energy sources | 0 | TWh | ageb_entwicklung-eev-ph_2019-10-10.xlsx |  |
| 986 | households | final energy consumption by all private households combined by energy source total | 651 | TWh | ageb_entwicklung-eev-ph_2019-10-10.xlsx |  |
| 987 | households | residual household reproduction rate | 0,003 | 1/100 | own estimate |  |
| 988 | households | avg yearly investment share of total income into sustainability improvement on buildings and cars | 0,025 | 1/100 | own estimate | source: interviews |

## Table 1: Workforce data

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 989 | workforce | labor force craftsmen total number of workers | 5218897 | 1 | destatis-53111 | Insgesamt |
| 990 | workforce | labor force craftsmen in main construction trade total number of workers | 727929 | 1 | destatis-53111 | Bauhauptgewerbe |
| 991 | workforce | labor force craftsmen in main construction trade masons and concrete workers | 372028 | 1 | destatis-53111 | Maurer und Betonbauer |
| 992 | workforce | labor force craftsmen in main construction trade carpenters | 89038 | 1 | destatis-53111 | Zimmerer |
| 993 | workforce | labor force craftsmen in main construction trade roofers | 94631 | 1 | destatis-53111 | Dachdecker |
| 994 | workforce | labor force craftsmen in main construction trade road builders | 123020 | 1 | destatis-53111 | Straßenbauer |
| 995 | workforce | labor force craftsmen in main construction trade heat cold and sound insulation workers | 13105 | 1 | destatis-53111 | Wärme-, Kälte- und Schallschutzisolierer |
| 996 | workforce | labor force craftsmen in main construction trade well builders | 4953 | 1 | destatis-53111 | Brunnenbauer |
| 997 | workforce | labor force craftsmen in main construction trade scafforders | 27766 | 1 | destatis-53111 | Gerüstbauer |
| 998 | workforce | labor force craftsmen in main construction trade concrete block and terrazzo builders | 3388 | 1 | destatis-53111 | Betonstein- und Terrazzohersteller |
| 999 | workforce | labor force craftsmen in finishing trade total number of workers | 1465916 | 1 | destatis-53111 | Ausbaugewerbe |
| 1000 | workforce | labor force craftsmen in finishing trade stove and air heating builders | 7722 | 1 | destatis-53111 | Ofen- und Luftheizungsbauer |
| 1001 | workforce | labor force craftsmen in finishing trade plasterers | 30886 | 1 | destatis-53111 | Stuckateure |
| 1002 | workforce | labor force craftsmen in finishing trade painters and varnishers | 207575 | 1 | destatis-53111 | Maler und Lackierer |
| 1003 | workforce | labor force craftsmen in finishing trade tinsmiths | 23999 | 1 | destatis-53111 | Klempner |
| 1004 | workforce | labor force craftsmen in finishing trade plumbers and heating engineers | 327340 | 1 | destatis-53111 | Installateur und Heizungsbauer |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1005 | workforce | labor force craftsmen in finishing trade electrical engineers | 445803 | 1 | destatis-53111 | Elektrotechniker |
| 1006 | workforce | labor force craftsmen in finishing trade joiners | 200352 | 1 | destatis-53111 | Tischler |
| 1007 | workforce | labor force craftsmen in finishing trade glaziers | 23390 | 1 | destatis-53111 | Glaser |
| 1008 | workforce | labor force craftsmen in finishing trade floor tilers | 98892 | 1 | destatis-53111 | Fliesen-, Platten- und Mosaikleger |
| 1009 | workforce | labor force craftsmen in finishing trade composition floor layers | 17467 | 1 | destatis-53111 | Estrichleger |
| 1010 | workforce | labor force craftsmen in finishing trade parquet layers | 15175 | 1 | destatis-53111 | Parkettleger |
| 1011 | workforce | labor force craftsmen in finishing trade roller blinds and sun shutter technicians | 17477 | 1 | destatis-53111 | Rollladen- und Sonnenschutztechniker |
| 1012 | workforce | labor force craftsmen in finishing trade interior decorators | 49838 | 1 | destatis-53111 | Raumausstatter |
| 1013 | workforce | workforce demand for yearly new installed solar PV capacity (10GW) | 70000 | 1 | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 1014 | workforce | workforce solar pv sector 2018 | 24000 | 1 | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 1015 | workforce | workforce lignite mining 2015 | 21000 | 1 | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |

## Table 1: Land-use and land-use change data

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 1016 | LULUC | landuse total area | 35737700 | ha | www.bfn.de | 2014 |
| 1017 | LULUC | landuse agriculture incl peat and heath | 18460700 | ha | www.bfn.de | 2014 |
| 1018 | LULUC | landuse agriculture incl peat and heath share | 0,5166 | 1/100 | www.bfn.de | 2014 |
| 1019 | LULUC | landuse forest woodland | 10930600 | ha | www.bfn.de | 2014 |
| 1020 | LULUC | landuse forest woodland share | 0,3059 | 1/100 | www.bfn.de | 2014 |
| 1021 | LULUC | landuse built environment buildings | 2502600 | ha | www.bfn.de | 2014 |
| 1022 | LULUC | landuse built environment buildings share | 0,07 | 1/100 | www.bfn.de | 2014 |
| 1023 | LULUC | landuse built environment infrastructure | 1807100 | ha | www.bfn.de | 2014 |
| 1024 | LULUC | landuse built environment infrastructure share | 0,0506 | 1/100 | www.bfn.de | 2014 |
| 1025 | LULUC | landuse inland waters | 847700 | ha | www.bfn.de | 2014 |
| 1026 | LULUC | landuse inland waters share | 0,0237 | 1/100 | www.bfn.de | 2014 |
| 1027 | LULUC | landuse cemeteries wasteland and other | 485000 | ha | www.bfn.de | 2014 |
| 1028 | LULUC | landuse cemeteries wasteland and other share | 0,0136 | 1/100 | www.bfn.de | 2014 |
| 1029 | LULUC | landuse recreational areas | 439700 | ha | www.bfn.de | 2014 |
| 1030 | LULUC | landuse recreational areas share | 0,0123 | 1/100 | www.bfn.de | 2014 |
| 1031 | LULUC | landuse industrial and mining land | 264300 | ha | www.bfn.de | 2014 |
| 1032 | LULUC | landuse industrial and mining land share | 0,0074 | 1/100 | www.bfn.de | 2014 |
| 1033 | LULUC | landuse change avg p day built environment buildings | 23,6 | ha/d | www.bfn.de | 2010-2013 |
| 1034 | LULUC | landuse change avg p day recreational areas | 22,9 | ha/d | www.bfn.de | 2010-2013 |
| 1035 | LULUC | landuse change avg p day built environment infrastructure | 16,7 | ha/d | www.bfn.de | 2010-2013 |
| 1036 | LULUC | landuse change avg p day industrial land | 9,3 | ha/d | www.bfn.de | 2010-2013 |
| 1037 | LULUC | landuse marginal costs of land and maintenance for ha of urban green | 238000 | €/ha | www.bfn.de | 2014 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1038 | LULUC | landuse marginal lost social benefit of living spance for ha of urban green | 450000 | €/ha | www.bfn.de | 2014 |
| 1039 | LULUC | landuse marginal social value for ha of urban green | 1049000 | €/ha | www.bfn.de | 2014 |

## Table 1: Population data

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 1040 | population | population Germany 2019 | 83019213 | persons | https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en | |
| 1041 | population | population EU-28 2019 | 51347167 | persons | https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en | |
| 1042 | population | population EU-27 2019 | 44682456 | persons | https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en | |
| 1043 | population | population contribution of Germany to EU-28 | 0,161682 | 1/100 | own estimate | |
| 1044 | population | population contribution of Germany to EU-27 | 0,185798 | 1/100 | own estimate | |
| 1045 | population | birth rates per woman 2018 | 1,57 | 1 | Destatis | |
| 1046 | population | birth rates per woman 2019 | 1,54 | 1 | Destatis | |
| 1047 | population | birth rate absolute 2018 | 787523 | 1 | Destatis | |
| 1048 | population | birth rate absolute 2019 | 778100 | 1 | Destatis | |
| 1049 | population | maturity time until founding household | 25 | a | own estimate | average age when children leave parents' household |

## Table 1: Transportation data

| no | sector | data | value | units | source | notes |
|---|---|---|---|---|---|---|
| 1050 | transportation | local traffic min | 0 | km | https://de.wikipedia.org/wiki/G%C3%BCterverkehr | |
| 1051 | transportation | local traffic max | 50 | km | https://de.wikipedia.org/wiki/G%C3%BCterverkehr | |
| 1052 | transportation | regional traffic min | 51 | km | https://de.wikipedia.org/wiki/G%C3%BCterverkehr | |
| 1053 | transportation | regional traffic max | 150 | km | https://de.wikipedia.org/wiki/G%C3%BCterverkehr | |
| 1054 | transportation | longdistance traffic min | 151 | km | https://de.wikipedia.org/wiki/G%C3%BCterverkehr | |
| 1055 | transportation | rail cargo volume of goods current max | 1800 | t | https://de.wikipedia.org/wiki/Schieneng%C3%BCterverkehr | |
| 1056 | transportation | rail cargo volume of goods planned max | 3600 | t | https://de.wikipedia.org/wiki/Schieneng%C3%BCterverkehr | |
| 1057 | transportation | inland waterway transport of goods volume min | 300 | t | https://de.wikipedia.org/wiki/Binnenschifffahrt | |
| 1058 | transportation | inland waterway transport of goods volume max | 10000 | t | https://de.wikipedia.org/wiki/Schubboot | |
| 1059 | transportation | trucking cargo volume current max | 40 | t | https://de.wikipedia.org/wiki/EuroCombi | |
| 1060 | transportation | trucking cargo volume planned max | 60 | t | https://de.wikipedia.org/wiki/EuroCombi | |
| 1061 | transportation | car new registrations 2010-2018 mean | 0,021549 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1062 | transportation | car new registrations 2010-2018 min | -0,042 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1063 | transportation | car new registrations 2010-2018 max | 0,088 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1064 | transportation | passenger km 2018 total mobility | 1,25736E | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1065 | transportation | passenger km 2018 total assisted mobility (excl. walking) | 1,22146E | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1066 | transportation | passenger km 2018 over land total | 1,11176E | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| 1067 | transportation | passenger km 2018 over land motorized individual transport | 9,348E+1 | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | page 218 |
| 1068 | transportation | passenger km 2018 over land public transport | 78890000 | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1069 | transportation | passenger km 2018 over land rail | 98070000 | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1070 | transportation | passenger km 2018 air travel total | 70400000 | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1071 | transportation | passenger km 2018 air travel inland | 10300000 | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1072 | transportation | passenger km 2018 bycicle | 39300000 | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1073 | transportation | passenger km 2018 walking | 35900000 | pkm | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1074 | transportation | passenger km 2018 over land total share of assisted mobility | 0,910189 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1075 | transportation | passenger km 2018 over land motorized individual transport share of assisted mobility | 0,765313 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1076 | transportation | passenger km 2018 over land public transport share of assisted mobility | 0,064586 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1077 | transportation | passenger km 2018 over land rail share of assisted mobility | 0,080289 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1078 | transportation | passenger km 2018 air travel total share of assisted mobility | 0,057635 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1079 | transportation | passenger km 2018 air travel inland share of assisted mobility | 0,008432 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1080 | transportation | passenger km 2018 bycicle share of assisted mobility | 0,032174 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1081 | transportation | passenger km mean growth 2010-2018 | 0,00727 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1082 | transportation | passenger km min growth 2010-2018 | -0,02 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1083 | transportation | passenger km max growth 2010-2018 | 0,02 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1084 | transportation | number of passengers 2018 over land total | 66650000 | persons | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1085 | transportation | number of passengers 2018 over land motorized individual transport | 54160000 | persons | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1086 | transportation | number of passengers 2018 over land public transport | 96200000 | persons | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1087 | transportation | number of passengers 2018 over land rail | 28700000 | persons | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1088 | transportation | number of passengers 2018 air travel total | 22260000 | persons | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1089 | transportation | number of passengers 2018 air travel inland | 23500000 | persons | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1090 | transportation | number of passengers 2018 bycicle | 9879000 | persons | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1091 | transportation | number of passengers 2018 walking | 21590000 | persons | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html |  |
| 1092 | transportation | total passenger km 2017 | 6,30E+11 | pkm | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf |  |
| 1093 | transportation | total passenger km 2015 | 9,58E+11 | pkm | https://www.adac.de/_mmm/pdf/statistik_zahlen_fakten_wissen_1016_208844.pdf |  |
| 1094 | transportation | total vehicle km of automobiles 2015 | 7,57E+11 | vkm | https://www.adac.de/_mmm/pdf/statistik_zahlen_fakten_wissen_1016_208844.pdf |  |
| 1095 | transportation | total vehicle km of automobiles 2015 | 6,19E+11 | vkm | https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/vk_inlaenderfahrleistung/vk_inlaenderfahrleistung_inhalt.html?nn=2351604 | alternative |
| 1096 | transportation | total vehicle km of automobiles 2016 | 6,26E+11 | vkm | https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/vk_inlaenderfahrleistung/vk_inlaenderfahrleistung_inhalt.html?nn=2351604 | alternative |
| 1097 | transportation | total vehicle km of automobiles 2017 | 6,31E+11 | vkm | https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/vk_inlaenderfahrleistung/vk_inlaenderfahrleistung_inhalt.html?nn=2351604 | alternative |
| 1098 | transportation | total vehicle km of automobiles 2018 | 6,31E+11 | vkm | https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/vk_inlaenderfahrleistung/vk_inlaenderfahrleistung_inhalt.html?nn=2351604 | alternative |

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|---|---|---|---|---|---|---|
| 1099 | transportation | total vehicle km of automobiles 2019 | 6,32E+11 | vkm | https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/vk_inlaenderfahrleistung/vk_inlaenderfahrleistung_inhalt.html?nn=2351604 | alternative |
| 1100 | transportation | total vehicle km of automobiles avg growth 2015-2019 | 3,29E+09 | vkm | own estimate | |
| 1101 | transportation | avg passengers per vehicle Germany 2015 | 1,478519 | p/v | www.bmvi.de/viz & https://www.kba.de/DE/Statistik/Kraftverkehr/VerkehrKilometer/vk_inlaenderfahrleistung/vk_inlaenderfahrleistung_inhalt.html?nn=2351604 | source: KBA + BMVi |
| 1102 | transportation | avg age cars Germany | 9,6 | a | https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html | |
| 1103 | transportation | avg mileage of cars Germany | 350000 | km | https://www.wer-weiss-was.de/t/gesamtlaufleistung-pkw-auslegung/2887819/3 and https://www.autozeitung.de/lebensdauer-motoren-192983.html | |
| 1104 | transportation | avg lifetime time of cars per manufacturer | 18 | a | https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html | |
| 1105 | transportation | BEV energy consumption per km avg | 0,2115 | kWh/km | https://www.adac.de/rund-ums-fahrzeug/tests/elektromobilitaet/stromverbrauch-elektroautos-adac-test/ | min 14,7 kWh max 27,6 kWh per 100km by ADAC test 2020 |
| 1106 | transportation | PHEV energy consumption per km (petrol) fuel based | 0,025 | l/km | own estimate | reference pick is highest value of current newest models for the average of current fleet: mercedes-benz.de on 10. June 2020 showing a fuel consumption range between 1,4 l/km and 2,6 l/km for their PHEV models |
| 1107 | transportation | PHEV energy consumption per km (petrol) fuel based | 0,2425 | kWh/km | own estimate | |
| 1108 | transportation | PHEV energy consumption per km electric based | 0,2115 | kWh/km | https://www.adac.de/rund-ums-fahrzeug/tests/elektromobilitaet/stromverbrauch-elektroautos-adac-test/ | min 14,7 kWh max 27,6 kWh per 100km by ADAC test 2020 |
| 1109 | transportation | PHEV share of electricty in total fuel consumption | 0,5 | 1/100 | own estimate | |
| 1110 | transportation | PHEV energy consumption per km combined 50/50 | 0,227 | kWh/km | own estimate | |
| 1111 | transportation | HEV energy consumption per km avg | 0,60528 | kWh/km | own estimate | assuming 20% efficiency gain on CEV |
| 1112 | transportation | EV energy charging losses | 0,15 | 1/100 | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | add to EV energy consumption |
| 1113 | transportation | avg annual driving performance | 15000 | km/a | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 1114 | transportation | EV one-time battery related ghg emissions from production in CO2 equivalents 2017 | 145000 | g/kWh | https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/aktuelle-fakten-zur-photovoltaik-in-deutschland.pdf | |
| 1115 | transportation | CEV avg fuel consumption (petrol) per km 2018 | 0,078 | l/km | https://de.statista.com/statistik/daten/studie/484054/umfrage/durchschnittsverbrauch-pkw-in-privaten-haushalten-in-deutschland/ | |
| 1116 | transportation | CEV avg fuel consumption (petrol) per km in kWh | 0,7566 | kWh/km | own estimate | |
| 1117 | transportation | CEV energy content (petrol) per liter | 9,7 | kWh/l | https://de.wikipedia.org/wiki/Motorenbenzin | |
| 1118 | transportation | CEV avg fuel price (petrol) per liter | 1,43 | EUR/l | https://de.wikipedia.org/wiki/Elektroauto#Deutschland | |
| 1119 | transportation | CEV avg fuel price (petrol) per kWh | 0,1474 | EUR/kWh | own estimate | |
| 1120 | transportation | CEV avg fuel consumption (diesel) per km 2018 | 0,07 | l/km | https://de.statista.com/statistik/daten/studie/484054/umfrage/durchschnittsverbrauch-pkw-in-privaten-haushalten-in-deutschland/ | |
| 1121 | transportation | CEV avg fuel consumption (diesel) per km in kWh | 0,728 | kWh/km | own estimate | |
| 1122 | transportation | CEV energy content (diesel) per liter | 10,4 | kWh/l | https://de.wikipedia.org/wiki/Dieselkraftstoff | |
| 1123 | transportation | CEV avg fuel price (diesel) per liter | 1,26 | EUR/l | https://de.wikipedia.org/wiki/Elektroauto#Deutschland | |
| 1124 | transportation | CEV avg fuel price (diesel) per kWh | 0,1212 | EUR/kWh | own estimate | |
| 1125 | transportation | BEV stock at 01.01.2020 | 82.767 | 1 | https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html | |
| 1126 | transportation | EV share new registrations 1. quarter 2020 | 0,037 | 1/100 | https://de.wikipedia.org/wiki/Elektroauto#Deutschland and KBA | |

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|---|---|---|---|---|---|---|
| 1127 | transportation | EV share new registrations 2019 | 0,018 | 1/100 | KBA | |
| 1128 | transportation | EV new registrations in 2019 | 53442 | 1 | https://www.kba.de/DE/Statistik/Fahrzeuge/Bestand/bestand_node.html | |
| 1129 | transportation | total new registrations 2019 private ownership | 1249011 | 1 | KBA | fz4_2018_KFZ_Neuzulassungen_Hersteller-Handelsname |
| 1130 | transportation | total new registrations 2019 total ownership | 3435778 | 1 | KBA | fz4_2018_KFZ_Neuzulassungen_Hersteller-Handelsname |
| 1131 | transportation | total new registrations 2019 total ownership | 0,363530 | 1/100 | KBA | fz4_2018_KFZ_Neuzulassungen_Hersteller-Handelsname |
| 1132 | transportation | avg sales price per new registration 2019 | 34000 | EUR | https://de.statista.com/statistik/daten/studie/36408/umfrage/durchschnittliche-neuwagenpreise-in-deutschland/ | |
| 1133 | transportation | avg sales price per new registration petrol | 31000 | EUR | own estimate | due to comparison from:<br>www.mercedes-benz.de<br>www.audi.de<br>www.bmw.de |
| 1134 | transportation | avg sales price per new registration diesel | 34000 | EUR | own estimate | due to comparison from:<br>www.mercedes-benz.de<br>www.audi.de<br>www.bmw.de |
| 1135 | transportation | avg sales price per new registration gas | 38000 | EUR | own estimate | due to comparison from:<br>www.audi.de |
| 1136 | transportation | avg sales price per new registration HEV | 38000 | EUR | own estimate | no source |
| 1137 | transportation | avg sales price per new registration PHEV | 41000 | EUR | own estimate | due to comparison from:<br>www.mercedes-benz.de<br>www.audi.de<br>www.bmw.de |
| 1138 | transportation | avg sales price per new registration BEV | 51000 | EUR | own estimate | due to comparison from:<br>www.mercedes-benz.de<br>www.audi.de<br>www.bmw.de |
| 1139 | transportation | avg yearly maintenance cost small car | 480 | EUR | https://www.verti.de/blog/auto-kosten.jsp and https://www.adac.de/infotestrat/autodatenbank/autokosten/autokosten-rechner/ | |
| 1140 | transportation | avg yearly maintenance cost medium car | 648 | EUR | https://www.verti.de/blog/auto-kosten.jsp and https://www.adac.de/infotestrat/autodatenbank/autokosten/autokosten-rechner/ | |
| 1141 | transportation | avg yearly maintenance cost large car | 972 | EUR | https://www.verti.de/blog/auto-kosten.jsp and https://www.adac.de/infotestrat/autodatenbank/autokosten/autokosten-rechner/ | |
| 1142 | transportation | avg yearly fixed cost small car | 744 | EUR | https://www.verti.de/blog/auto-kosten.jsp and https://www.adac.de/infotestrat/autodatenbank/autokosten/autokosten-rechner/ | |
| 1143 | transportation | avg yearly fixed cost medium car | 1032 | EUR | https://www.verti.de/blog/auto-kosten.jsp and https://www.adac.de/infotestrat/autodatenbank/autokosten/autokosten-rechner/ | |
| 1144 | transportation | avg yearly fixed cost large car | 1848 | EUR | https://www.verti.de/blog/auto-kosten.jsp and https://www.adac.de/infotestrat/autodatenbank/autokosten/autokosten-rechner/ | |
| 1145 | transportation | CEV avg fuel price CNG per kg | 1,13 | EUR/kg | https://de.wikipedia.org/wiki/Erdgas | |
| 1146 | transportation | CEV avg fuel price CNG per kWh | 0,085 | EUR/kWh | own estimate | |
| 1147 | transportation | CEV avg fuel consumption (CNG) per km | 0,043 | kg/km | https://www.focus.de/auto/fahrberichte/dauertest-skoda-octavia-g-tec-100-kilometer-kosten-vier-euro-so-schlaegt-sich-der-erdgas-skoda-im-dauertest_id_7502654.html | |
| 1148 | transportation | CEV avg fuel consumption (CNG) per km in kWh | 0,5719 | kWh/km | own estimate | |
| 1149 | transportation | CEV avg fuel price LPG per liter | 0,55 | EUR/l | https://www.fluessiggas1.de/fluessiggas_umrechnung_kwh_m3_liter_kg/ | |
| 1150 | transportation | CEV avg fuel price LPG per kWh | 0,0767 | EUR/kWh | own estimate | |
| 1151 | transportation | CEV avg fuel consumption (LPG) per km | 0,0936 | l/km | https://www.adac.de/_mmm/pdf/ADAC%20Kostenvergleich%20Umr%C3%BCstung%20Gasfahrzeuge_47083.pdf | avg 20% more consumption than in petrol mode |
| 1152 | transportation | CEV avg fuel consumption (LPG) per km in kWh | 0,671112 | kWh/km | own estimate | |
| 1153 | transportation | CEV conversion LPG m3 to liter | 3,93 | l/m3 | https://www.fluessiggas1.de/fluessiggas_umrechnung_kwh_m3_liter_kg/ | |
| 1154 | transportation | CEV conversion LPG m3 to kg | 0,4968 | kg/m3 | https://www.fluessiggas1.de/fluessiggas_umrechnung_kwh_m3_liter_kg/ | |

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|---|---|---|---|---|---|---|
| 1155 | transportation | electrification level of public transport | 0,331385 | 1/100 | https://aiomag.de/elektrifizierung-des-staedtischen-busverkehrs-hier-fahren-e-busse-18935 | see 'Z11states_geneerated!ES' + destatis_46100-0021 |
| 1156 | transportation | share of omnibus in public transport | 0,668614 | 1/100 | https://aiomag.de/elektrifizierung-des-staedtischen-busverkehrs-hier-fahren-e-busse-18936 | |
| 1157 | transportation | electrification level of public transport avg growth rate target | 0,033430 | 1/100 | https://aiomag.de/elektrifizierung-des-staedtischen-busverkehrs-hier-fahren-e-busse-18935 and own estimate | 0 to 100% by 2040 |
| 1158 | transportation | electrification level of railway system | 0,609 | 1/100 | https://dipbt.bundestag.de/doc/btd/19/160/1916019.pdf | |
| 1159 | transportation | electrification level of railway system target | 0,7 | 1/100 | https://dipbt.bundestag.de/doc/btd/19/160/1916019.pdf | |
| 1160 | transportation | electrification level of railway system avg growth rate | 0,002 | 1/100 | https://dipbt.bundestag.de/doc/btd/19/160/1916019.pdf | |
| 1161 | transportation | electrification level of passenger rail | 0,98 | 1/100 | ? somewhere on forschungsinformationssystem.de | |
| 1162 | transportation | electrification level of air | 0 | 1/100 | own estimate | |
| 1163 | transportation | electrification level of bycicle | 0,054 | 1/100 | https://nationaler-radverkehrsplan.de/de/node/21072 | |
| 1164 | transportation | electrification level of bycicle avg growth rate | 0,01 | 1/100 | https://nationaler-radverkehrsplan.de/de/node/21072 | |
| 1165 | transportation | expected transportation demand growth rate for car avg | 0,0164 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1166 | transportation | expected transportation demand growth rate for road-based public transport avg | -0,0039 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1167 | transportation | expected transportation demand growth rate for rail passenger transport 2015-2030 | 0,22 | 1/100 | https://www.forschungsinformationssystem.de/servlet/is/342736/ and https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1168 | transportation | expected transportation demand growth rate for rail passenger transport yearly rate | 0,0167 | 1/100 | https://www.forschungsinformationssystem.de/servlet/is/342736/ and https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1169 | transportation | expected transportation demand growth rate for air avg | 0,0331 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1170 | transportation | expected transportation demand growth rate for bicycle avg | 0,0379 | 1/100 | https://www.bmvi.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2019-pdf.html | |
| 1171 | transportation | assumed occupancy rate public transport total avg | 0,19 | 1/100 | https://www.umweltbundesamt.de/bild/vergleich-der-durchschnittlichen-emissionen-0 | 2018 |
| 1172 | transportation | assumed occupancy rate public transport bus avg | 0,19 | 1/100 | https://www.umweltbundesamt.de/bild/vergleich-der-durchschnittlichen-emissionen-0 | 2018 |
| 1173 | transportation | assumed occupancy rate public transport rail avg | 0,19 | 1/100 | https://www.umweltbundesamt.de/bild/vergleich-der-durchschnittlichen-emissionen-0 | 2018 |
| 1174 | transportation | assumed occupancy rate rail avg | 0,56 | 1/100 | https://www.forschungsinformationssystem.de/servlet/is/343659/ and https://www.sileo-ebus.com/ | |
| 1175 | transportation | assumed occupancy rate air total avg | 0,752392 | 1/100 | http://www.umweltbundesamt.de/ | UBA 2020 |
| 1176 | transportation | assumed occupancy rate air international avg | 0,76 | 1/100 | http://www.umweltbundesamt.de/ | UBA 2020 |
| 1177 | transportation | air transport energy consumption per pkm international | 0,05 | l/pkm | https://www.vcd.org/fileadmin/user_upload/Redaktion/Themen/Flugverkehr/NGO_Luftverkehrskonzept_7-2015.pdf | |
| 1178 | transportation | assumed occupancy rate air inland avg | 0,708 | 1/100 | http://www.umweltbundesamt.de/ | UBA 2020 |
| 1179 | transportation | air transport energy consumption per pkm inland | 0,08 | l/pkm | https://www.vcd.org/fileadmin/user_upload/Redaktion/Themen/Flugverkehr/NGO_Luftverkehrskonzept_7-2015.pdf | |
| 1180 | transportation | air transport share inland flights | 0,146306 | 1/100 | own estimate | |
| 1181 | transportation | CEV conversion LPG liter to kg | 0,509 | kg/l | https://www.fluessiggas1.de/fluessiggas_umrechnung_kwh_m3_liter_kg/ | |
| 1182 | transportation | car new registrations 2019 target shares | - | - | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/pm01_2020_n_12_19_pm_komplett.html?nn=2562684 | |
| 1183 | transportation | car new registrations 2020 Jan share petrol | 0,515 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html | |
| 1184 | transportation | car new registrations 2020 Jan share diesel | 0,326 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html | |
| 1185 | transportation | car new registrations 2020 Jan share gas | 0,0035 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html | |
| 1186 | transportation | car new registrations 2020 Jan share HEV | 0,09 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html | |
| 1187 | transportation | car new registrations 2020 Jan share PHEV | 0,035 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html | |
| 1188 | transportation | car new registrations 2020 Jan share BEV | 0,03 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html | |

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|---|---|---|---|---|---|
| 1189 | transportation | car new registrations 2020 Feb share petrol | 0,521 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1190 | transportation | car new registrations 2020 Feb share diesel | 0,316 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1191 | transportation | car new registrations 2020 Feb share gas | 0,003 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1192 | transportation | car new registrations 2020 Feb share HEV | 0,09 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1193 | transportation | car new registrations 2020 Feb share PHEV | 0,035 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1194 | transportation | car new registrations 2020 Feb share BEV | 0,034 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1195 | transportation | car new registrations 2020 Mar share petrol | 0,5 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1196 | transportation | car new registrations 2020 Mar share diesel | 0,316 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1197 | transportation | car new registrations 2020 Mar share gas | 0,002 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1198 | transportation | car new registrations 2020 Mar share HEV | 0,09 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1199 | transportation | car new registrations 2020 Mar share PHEV | 0,044 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1200 | transportation | car new registrations 2020 Mar share BEV | 0,048 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1201 | transportation | car new registrations 2020 Apr share petrol | 0,499 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1202 | transportation | car new registrations 2020 Apr share diesel | 0,321 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1203 | transportation | car new registrations 2020 Apr share gas | 0,004 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1204 | transportation | car new registrations 2020 Apr share HEV | 0,091 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1205 | transportation | car new registrations 2020 Apr share PHEV | 0,046 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1206 | transportation | car new registrations 2020 Apr share BEV | 0,038 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1207 | transportation | car new registrations 2020 May share petrol | 0,511 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1208 | transportation | car new registrations 2020 May share diesel | 0,316 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1209 | transportation | car new registrations 2020 May share gas | 0,003 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1210 | transportation | car new registrations 2020 May share HEV | 0,096 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1211 | transportation | car new registrations 2020 May share PHEV | 0,04 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1212 | transportation | car new registrations 2020 May share BEV | 0,033 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1213 | transportation | car new registrations 2020 Jun share petrol | 0,515 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1214 | transportation | car new registrations 2020 Jun share diesel | 0,306 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1215 | transportation | car new registrations 2020 Jun share gas | 0,005 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1216 | transportation | car new registrations 2020 Jun share HEV | 0,088 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1217 | transportation | car new registrations 2020 Jun share PHEV | 0,049 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1218 | transportation | car new registrations 2020 Jun share BEV | 0,037 | 1/100 | https://www.kba.de/DE/Presse/Pressemitteilungen/2020/Fahrzeugzulassungen/fahrzeugzulassungen_node.html |
| 1219 | transportation | buyer's premiums on cars phev min | 5625 | EUR | https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-konjunkturpaket-beschlossen.html;jsessionid=4856A7FD65852AB1545CDD2C2C10011F.delivery2-replication and https://www.meinauto.de/lp-abwrackpraemie |
| 1220 | transportation | buyer's premiums on cars phev max | 6750 | EUR | https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-konjunkturpaket-beschlossen.html;jsessionid=4856A7FD65852AB1545CDD2C2C10011F.delivery2-replication and https://www.meinauto.de/lp-abwrackpraemie |
| 1221 | transportation | buyer's premiums on cars bev min | 7500 | EUR | https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-konjunkturpaket-beschlossen.html;jsessionid=4856A7FD65852AB1545CDD2C2C10011F.delivery2-replication and https://www.meinauto.de/lp-abwrackpraemie |

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| 1222 | transportation | buyer's premiums on cars bev max | 9000 | EUR | https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-konjunkturpaket-beschlossen.html;jsessionid=4856A7FD65852AB1545CDD2C2C10011F.delivery2-replication and https://www.meinauto.de/lp-abwrackpraemie |
| 1223 | transportation | buyer's premiums on cars deadline | 31.12.21 | - | https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Schlaglichter/Konjunkturpaket/2020-06-03-konjunkturpaket-beschlossen.html;jsessionid=4856A7FD65852AB1545CDD2C2C10011F.delivery2-replication and https://www.meinauto.de/lp-abwrackpraemie |
| 1224 | transportation | expected bev amount in total car fleet 2022 | 1000000 | 1 | https://www.bmwi.de/Redaktion/DE/Dossier/elektromobilitaet.html |
| 1225 | transportation | bev stock 2019 | 82767 | 1 | own estimate |
| 1226 | transportation | bev new registrations 2019 | 61829 | 1 | own estimate |
| 1227 | transportation | outstanding bev registrations to make 2022 target | 855404 | 1 | own estimate |
| 1228 | transportation | bev required share on new registrations per year to make 2022 target | 0,124484 | 1/100 | own estimate |
| 1229 | transportation | bev stock scenario target 2030 | 10000000 | 1 | https://www.focus.de/auto/elektroauto/klimaschutz-im-verkehr-scheuer-sieht-gewaltige-herausforderung_id_10442221.html and https://www.spiegel.de/wirtschaft/soziales/verkehrsministerium-will-zehn-millionen-e-autos-bis-2030-a-1274272.html |
| 1230 | transportation | bev new registrations required per year post 2022 target to meet 2030 target | 1125000 | 1 | own estimate |
| 1231 | transportation | bev new registrations required per year post 2022 target to meet 2030 target share of total | 0,327436 | 1/100 | own estimate |