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Data Documentation Erdgas-BRidGE – Input data for modeling the power, building, and gas sector

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Abbreviations

BNetzA	Bundesnetzagentur
DWD	Deutscher Wetterdienst
DH	District heating
EC	European Commission
ENTSO-E	European Network of Transmission System Operators
ENTSO-G	European Network of Transmission System Operators for Gas
EU	European Union
GDS	Government Digital Service
GHG	Greenhouse gas
IEA	International Energy Agency
KfW	Kreditanstalt für Wiederaufbau
LNG	Liquified natural gas
OECD	Organisation for Economic Co-operation and Development
UBA	Umweltbundesamt
UK	United Kingdom
WP	Work package

1 Introduction

A transparent documentation of scientific work is crucial for the gain and dissemination of knowledge. Therefore, the objective of this data documentation is the provision of a transparent compilation of the research carried out in the project Erdgas-BRidGE (Erdgas - Bedeutung und zukünftige Rolle in der deutschen (German) Energiewende). The project, which is investigating the role of natural gas in the German energy transition, especially as a bridging fuel, is a joint effort by Technische Universität Dresden and Energiewirtschaftliches Institut an der Universität zu Köln gGmbH (EWI). It looks at both, the natural gas demand side, as well as the supply side. While the work on the demand side focuses on the electricity and the household heating sector, the work that is focusing on the supply side distinguishes between upstream and mid-stream supply and includes the transport of natural gas. Figure 1 gives a schematic overview of the project structure. The project is funded by the German Federal Ministry for Economic Affairs and Energy (grant numbers: 03ET4055A and 03ET4055B).

This document provides a documentation of the data collected and processed in the course of the project. In Chapter 2 the data concerned with obtaining gas demand is summarized. Chapter 2.1 describes data related to the natural gas demand in energy scenarios retrieved for a meta-analysis. In Chapter 2.2 you find data essential to model the electricity market when aiming to analyze the gas demand from the power sector, such as sources of power plant data including the parameters relevant for electricity market modeling or demand structures. Chapter 2.3 describes a database of the German building stock including installed systems for domestic hot water, heat and electricity supply, relevant when aiming to model future developments of household heating systems. Chapter 3 contains the data related to the gas supply. In Chapter 3.1 you find a description of a Python Tool for downloading and processing data on capacity bookings in the EU's gas market, relevant when aiming to access the impact of such bookings.[1] Chapter 3.2 describes data required when aiming to investigate uncertainties in the long-term supply of natural gas in Europe. Hence on the one hand relevant data to access this question, like natural gas demand, supply and flows is provided. On the other hand a description and examples are given on how uncertainties can be assessed using a numerical model. Finally, Chapter 4 contains some closing remarks and gives an overview of further works within the research project Erdgas-BRidGE.

[1]The Pyhton Tool is available at https://doi.org/10.5281/zenodo.4420042.

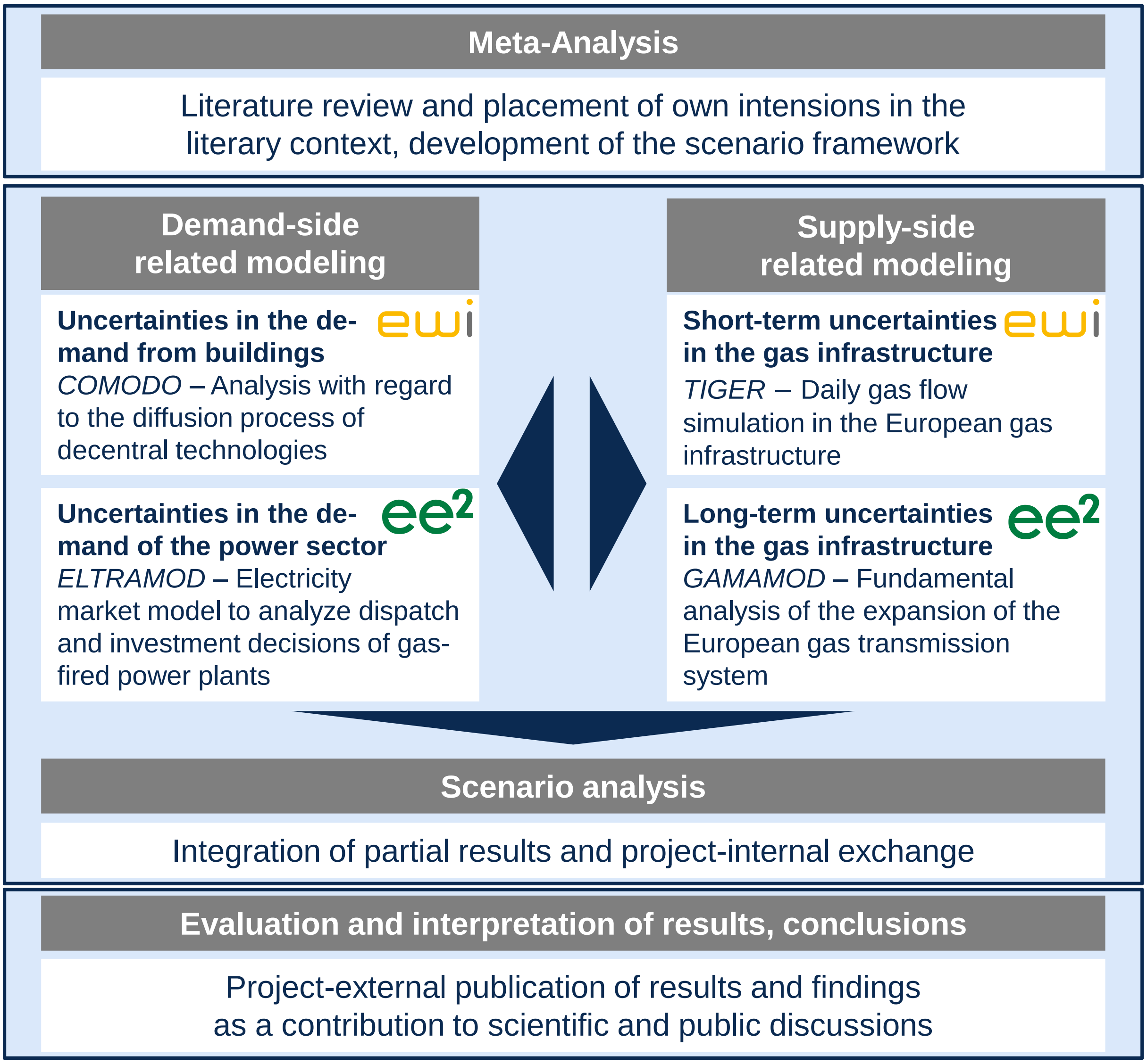

Figure 1: Overview of the project setup Erdgas-BRidGE.

Own illustration.

All subsections describe briefly the motivation of including the data in the particulat model and explain how the data is processed. Furthermore, we provide the compiled or further processed data with separate table sheets under the DOI https://doi.org/10.5281/zenodo.4420042, file name Erdgas-BRidGE_Dataset (2021).xlsx. By disclosing our data we aim at increasing the transparency of our research, inspiring other researchers when they have to process data as as well as supporting the researcher community by providing processed data required for a range of research questions.

2 Data for demand-side related modeling

2.1 Gas demand in energy scenarios

In order to establish a reference point for the trajectory of natural gas demand and its underlying causes, an extensive meta-analysis of various publications, which model possible future developments of the energy system under diffent underlying assumptions, was conducted. A central point in interpretating the scenario results of the respective publications concerning the future role of natural gas involves examining the assumptions associated with different decarbonization strategies. The indications made in the respective publications provided a reference point for evaluating and contextualising the results attained in the project. The meta-analysis from Scharf et al. (undated a), prepared within the scope of the Erdgas-BRidGE project, examines the future role of natural gas in Germany in terms of consumption levels against the backdrop of five identified decarbonization strategies. The analysis considers 36 scenarios from eleven publications and compares the findings obtained with the results from other related meta-analyses. With data sheet A1 of our repository, we provide the collected scenario results on primary energy consumption of natural gas indicated by the selected scenarios analysed. Data sheet A2 contains all other scenario data, which are valuable for assessing the impact of the different decarbonization strategies on natural gas consumption. These include primary energy consumption of fossil coal and oil, gross natural gas-fired power generation, gross power generation from renewable energy sources and absolute greenhouse gas emissions as well as the associated relative reduction compared to levels in 1990.

2.2 Database for electricity market modeling to analyze the gas demand from the power sector

Power market modeling of forward-looking scenarios requires exogenous data with respect to future developments, including, e.g., learning curve effects, behavioral changes of customers, etc. The following compilation gives an overview of relevant data inputs for analyzing the power market sector within the Erdgas-BRidGE research project. Thus, for each data set a short description is provided and the relevant sources are referenced. All sources are publicly available and – except for the data from the International Energy Agency – freely accessible. Data from the International Energy Agency is available in the OECD iLibrary.

Power plant data

Representation of the existing power plant fleet - When applying a brown-field approach, i.e., the model incorporates existing plants and does not start with zero installed capacities as in a green-field approach, forward-looking models require a future projection of the current power plant fleet, e.g., availabilities, capacities and efficiencies of existing units. One customary method employed to address this issue involves rolling forward the units of the historical fleet with reference lifetimes as in, e.g., Ladwig (2017) and Gerbaulet & Lorenz (2017). This entails determining the commissioning year of all units of the existing power plant fleet. Reference lifetimes of the respective technologies may be sourced from, e.g., IEA (2015).[2]

Given the commissioning year and the reference lifetimes, the existing fleet may be extrapolated into the future, removing the capacities of units that would have exceeded their life span in the year under investigation and subsequently aggregating the remaining power station capacities if desired, e.g., to limit computational burden. Moreover, phase-outs of certain technologies, e.g., nuclear or coal, should be taken into account when rolling forward the existing fleet. Based on the existing plants' lifetimes and phase-outs considered, the model endogenously determines investment in new capacities of technologies. Several publicly available sources (government agencies, research institutions, open collaboration projects, network operators, associations of operators, NGOs) provide usable power plant data that can be compiled and validated making sure to avoid redundancy. Table 1 provides an overview of different power plant data sources. It should be noted that unofficial sources, especially those which are collaborative or NGO-based, should be used with the required diligence and, if possible, further validated with other sources. Similarly, sources providing countrywise aggregated capacities may be used as a means of validation for the unit-specific data collected.

Economic data of power plant investments - The Energy Technology Reference Indicator Projections of the Joint Research Centre 2014 (Weidner et al. (2014)) indicate values needed for future plant investments, especially initial CapEx, operation and maintenance costs and efficiency rates. It specifies projected reference values in ten year intervals for the period between 2020 and 2050.

[2]For further analyses of plant lifetimes in Germany, the authors refer to Markewitz et al. (2018), who carry out a comprehensive analysis of plant lifetimes, comparing reference indicators from a literature review with their own analysis of historical developments in the power plant fleet.

Table 1: Overview of various power plant data sources.

Type of Source	Citation	Country/ies	Aggregation Level (National aggregates or units)	Provides the year of commissioning	Provides district heating related sizes
Official national and supranational	BNetzA (2020)	Germany, Austria, Luxembourg	Units	Yes	No
	UBA (2020)	Germany	Units > 100 MW	Yes	Yes
	Eurostat (2019)	EU28	Countrywise aggregated	No	Yes
	GDS (2019)	United Kingdom	Units	Yes	No
	Institut Luxembourgeois de Régulation (2018)	Luxembourg	Countrywise aggregated	No	No
	Energy Authority (2020)	Finland	Units	No	Yes
	Ministerio de Industria, Comercio y Turismo (2020)	Spain	Units	Yes	No
Research-based	Kunz et al. (2018)	Germany	Units	Yes	Yes
	Neon Neue Energieökonomik et al. (2020)	Germany, Netherlands, France, Poland, Czech Republic, Switzerland, Italy, Finland, Spain, United Kingdom, Norway, Sweden, Slovakia, Slovenia, Austria, Denmark	Units	Yes	No
	Byers et al. (2018)	Worldwide	Units	Yes	No
Collaborative	Wikipedia (2020)	Worldwide	Units	Yes	Yes
	Global Plant Observatory (2020)	Worldwide	Units	Yes	Yes
Operator- or association-based	La Société Opendatasoft (2019)	France	Units	Yes	No
	International Atomic Energy Agency (2020)	Worldwide	Units (only nuclear stations)	Yes	No
	Elia (2020)	Belgium	Units	No	No
	ENTSO-E (2019)	Europe-wide	Countrywise aggregated	No	No
NGO-based	Europe Beyond Coal (2020)	Europe-wide	Units (lignite and hard coal only)	Yes	No

Intrayear resolution on input data

Electricity - Power demand profiles should take into account future developments in terms of annual demand, behavioral changes of electricity consumers and demand-side management measures. The Reflex Project data repository (Zöphel et al. (2019)) provides future load curves on a country basis in ten year intervals for the period between 2030 and 2050 that consider future developments. Countries included comprise the EU-28, Norway, Switzerland and the Balkan countries.

Feed-in Profiles of weather-dependent renewable energy sources - Historical national feed-in profiles are provided by the Transparency Platform of the European Network of Transmission System Operators for Electricity (ENTSO-E (2020)). As for every member state, the platform provides installed capacities on an annual basis and hourly generation curves of technologies. Future feed-in profiles can be derived based on historical data scaled with the generation capacity for the respective model scenario.

Power plant availabilities - Monthly availability factors of power plant technologies are provided by the LKD-EU project's database (Kunz et al. (2018)). Although the availabilities the repository provides relate to the year 2015, a comparison with values from older sources, e.g., Gaidosch (2008), reveals that the pattern of monthly factors remains similar over time. Thus, the profiles are assumed to be valid for future scenarios. The monthly time series of availabilities can be scaled with an annual factor when backtesting the model on the chosen base year.

District heat demand profiles - As the literature (see, e.g., Felten (2020) and Scharf et al. (unpublished b)) demonstrates, the implementation of district heating into power system models is worth considering, since the demand of district heat affects the dispatch of cogeneration plants and the overall model output. Kunz et al. (2018) provide hourly district heat demand curves for Germany, Austria, Belgium, Czech Republic, Denmark, France, Luxembourg, the Netherlands, Norway, Poland, and Sweden in their data repository, and describe the underlying methodology used to derive them. For Germany, the authors provide time series data for the ten cities with the hightest annual district heat demand, an aggregated industrial curve and an aggregated residual demand curve. All data made available is based on the year 2015. The approach used to derive the data incorporates daily temperature time series and a social component, represented by a relative hourly profile. Own calculations peformed indicate that 2017 is suitable to use as a representative year in terms of temperature time series and thus the profile lends itself to being deployed in modeling future scenarios.[3] With this being the case, the approach in Kunz et al. (2018) is modified and adapted to the year 2017.

Hereby, the objective is to obtain an hourly heat input time series for each individual district heating network. The curve represents the heat demand to be met by the district heat producing technologies connected to the network. The steps toward deriving the individual load curves is visualized in Figure 2 and described in the following. Data sheet B6 of the associated data repository provides the resulting district heating load curves.

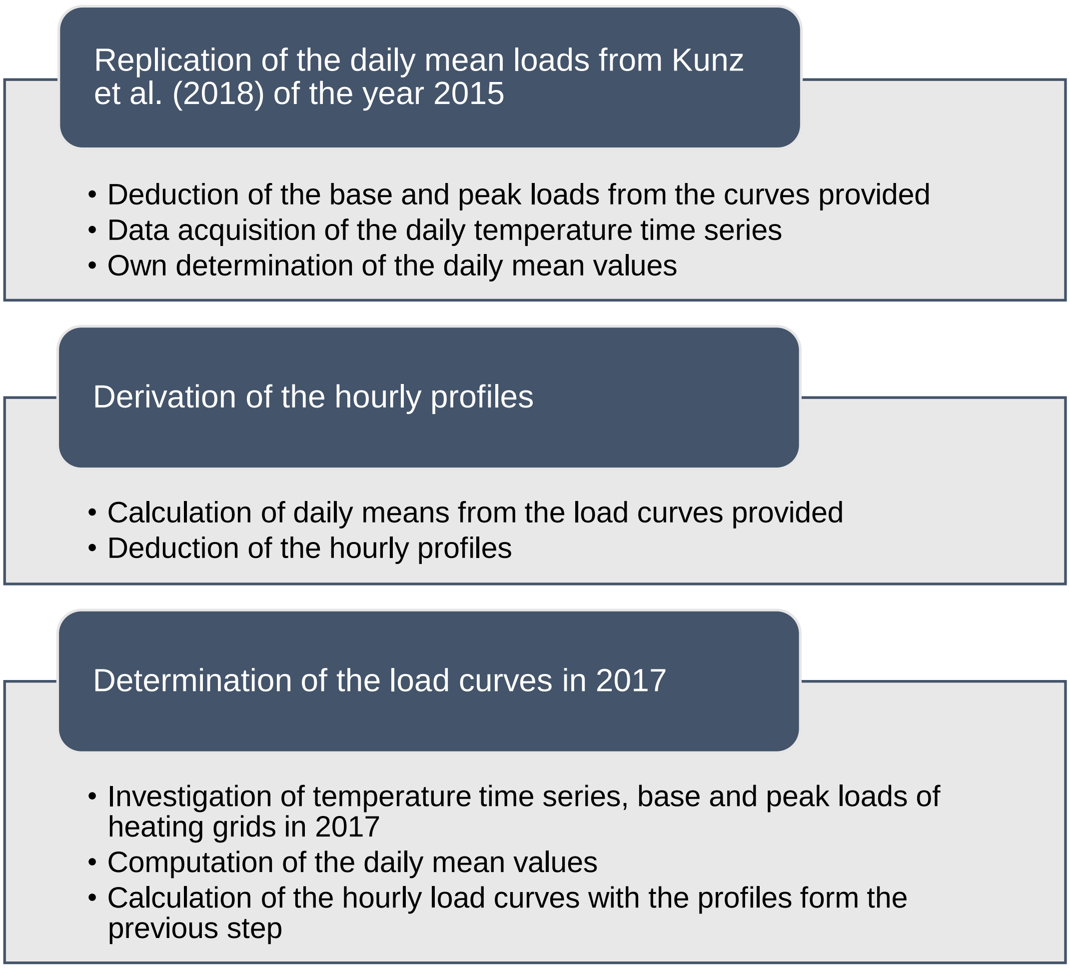

Figure 2: Steps toward obtaining district heating load curves.

Own illustration.

[3]The method applied to identify representative time series is Partitioning Around Medoids as described by Kaufman and Rousseeuw (1987). The analysis entails temperature time series relating to all the considered German cities from 2009 to 2018.

In an initial step, the profiles provided by Kunz et al. (2018) are reproduced using their approach and data from the various sources referenced by the authors. Daily temperature time series are derived from National Centers for Environmental Information (Menne et al. (2019)) and Deutscher Wetterdienst (DWD (2019)). National Centers for Environmental Information constitutes the primary source as Kunz et al. (2018) reference this platform. Deutscher Wetterdienst is used for German networks in the case that weather stations corresponding to the particular city in the respective network could not be identified. For the aggregated networks in countries outside of Germany, temperature data for cities with a representative size is retrieved. For both aggregated German district heating networks, a representative temperature time series is specified. Based on the daily averages deduced from the load curves provided by Kunz et al. (2018), in a second step, hourly profiles are determined by calculating the percentage variation around the daily mean. In a third step, annual 2017 demand values of all the considered district heating networks are investigated from the heating network operators. In the case that the source only indicates final demand values, annual sums of heat fed into the network are determined with loss coefficients of the corresponding federal state, obtained from AGFW (2017). German residual demand is obtained from the final heat consumption of residentials plus commercial and public services from IEA (2019a), adding the network loss calculated considering the nation-wide average network loss from AGFW (2017) and subtracting the demand of the disaggregated networks. Source of annual demand of all the other aggregated networks is the respective level of heat energy supplied from IEA (2019a), where German annual industrial demand is the heat energy supplied according to IEA (2019a) minus the annual consumption values of all the other German networks. The ratio of the annual demand in 2017 to that in 2015 reported in Kunz et al. (2018) is used to determine growth or reduction factors of district heat demand in the respective networks. The growth or reduction factor is used to scale the 2015 base and peak demand of a network deduced from the load curves provided by Kunz et al. (2018), assuming that both indications change with the rise or drop in annual consumption. Utilizing the hourly profiles and the temperature time series of 2017, the hourly load curves for 2017 are simulated based on the approach described by Felten et al. (2017) and Kunz et al. (2018). Annual sums of the simulated load curves are compared with the historical annual consumption values and depending on their degree of accuracy, the curves are adjusted with a correction factor in order to align the simulated curves with the historical annual demand values.

In Figure 3, the empirically obtained profiles for 2015 and 2017 and the profile for 2015 provided in Kunz et al. (2018) as well as the associated temperature time series are depicted for the district heating grid of the city of Hamburg. On the primary y-axis, the load curve for 2015 from Kunz et al. (2018), the replicated load curve of their reference year and the empirically derived load curve for the year 2017 are plotted. On the secondary y-axis, the associated daily average temperatures of both considered years are plotted.

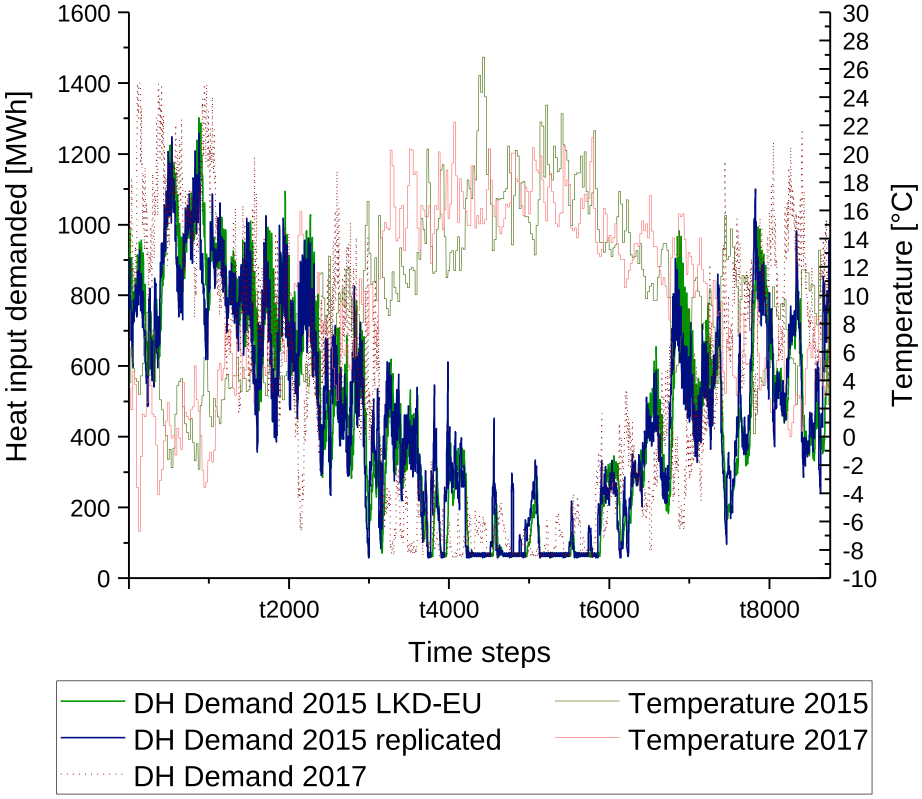

Figure 3: Overview of temperature and district heat time series of 2015 and 2017 for the city of Hamburg.

Own illustration. Data sources: Kunz et al. (2018), Menne et al. (2019).

Annual resolution on input data

Electricity - The forward-looking demand curves from Zöphel et al. (2019) entail annual consumption levels. Besides the annual sums from Zöphel et al. (2019), data sheet B3 of the data repository provides annual consumption levels for Germany and data sheet B2 aggregated EU-28 data from various other sources, which allows for comparing different scenario results. For country-specific data outside of Germany, the authors refer to Zöphel et al. (2019), who provide data of their scenarios for all countries included in their model (EU member states (including the UK), Switzerland, Norway, and the Balkan countries) as well as to EC (2016a), EC (2016b), EC (2019a), and EC (2019b), which provide data of different scenarios for each member state of the European Union, including the UK.

District heat - Future load curves may be obtained by scaling the hourly profiles of the year 2017 with growth or reduction factors from literature. However, specific scenario data of district heat demand for several countries are rarely available. Data sheets B5 and B6 of the data repository contains annual final energy demand for district heat of EU-28 and Germany from various sources. For country-specific data of other countries, the authors again refer to EC (2016a), EC (2016b), EC (2019a) and EC (2019b), which provide data of different scenarios for each member state of the European Union, including the UK.

Greenhouse gas emissions - Due to current regulations, it is important to limit annual GHG emissions of the power sector in the model. Several sources indicate future GHG emission reduction levels for the European Union. The EU Low Carbon Roadmap (EC (2011)) provides sector-specific overall targets for all member states. Data sheet B1 of the data repository compares them with annual GHG emission reduction levels from various sources with reference to the European Union (including the UK).[4]

Potentials of renewable capacities - Mainly due to land-use restrictions, renewables' potentials are limited. Scholz (2012) provides country-specific potentials (installed capacities/annual generation volumes). The dataset can be used to constrain the model's investments in renewable energy capacities.

Discussion and final remarks

This chapter provided a comprehensive overview of possible data sources which are useful for both scenario-based as well as historically based (oriented towards the past) electricity market modeling. For the power market, most of the required data is readily available. However, data on some elements is relatively scarce, making it challenging to contexualise the data sources used. This is particularly true for availability factor time series of power plant technologies, potentials of renewable energy sources and district heating profiles. Especially for district heating, actual time series data could not be collected so that a validation of the

[4]Base for the determination of GHG emissions of 1990 in the later EU28 from the power sector is the indication of energy-related GHG emissions from electricity generation and district heating of 2005 from EC 2016a and the relative reduction achieved in 2005 according to the the EU Low Carbon Roadmap (EC 2011) of seven percent. Also the International Energy Agency (IEA (2012)) provides a GHG emission level which is in the range of the so determined quantity, used as the base for the scenarios from the World Energy Outlook 2019 (IEA (2019b)).

determined curves with real data is not possible. Another point of critique is that the disaggregated district heating networks only accounts for one fourth of total annual demand. Furthermore, the data from the ENTSO-E - although widely used in literature – exhibits certain deficits with respect to its data quality. For an extensive evaluation of the data from the ENTSO-E Transparency Platform, the authors refer to Hirth et al. (2018).

2.3 Database of the German building stock including installed systems for domestic hot water, heat and electricity supply

Motiviation

In order to allow a detailed modeling of investment decisions of households in energy supply systems and the resulting demand for gas in the household sector, it is necessary to derive the existing building stock including installed technologies. There are various sources for representative buildings and households for the German building stock. However, no sources were available that link representative buildings to the stock of installed technologies. In the course of the project a new dataset was created. The aim was to represent not only the existing residential buildings in Germany, but also the distribution of installed supply systems of these buildings in the year 2019. Such data is not only necessary for this project but could also be useful to answer other research questions. With the help of the data set, representative buildings can be defined to investigate their energy management or investment behaviour or, for example, the influence of refurbishment measures.

The construction of the data set consists of several steps, as shown in Figure 4. The individual steps of the data processing are explained in detail below.

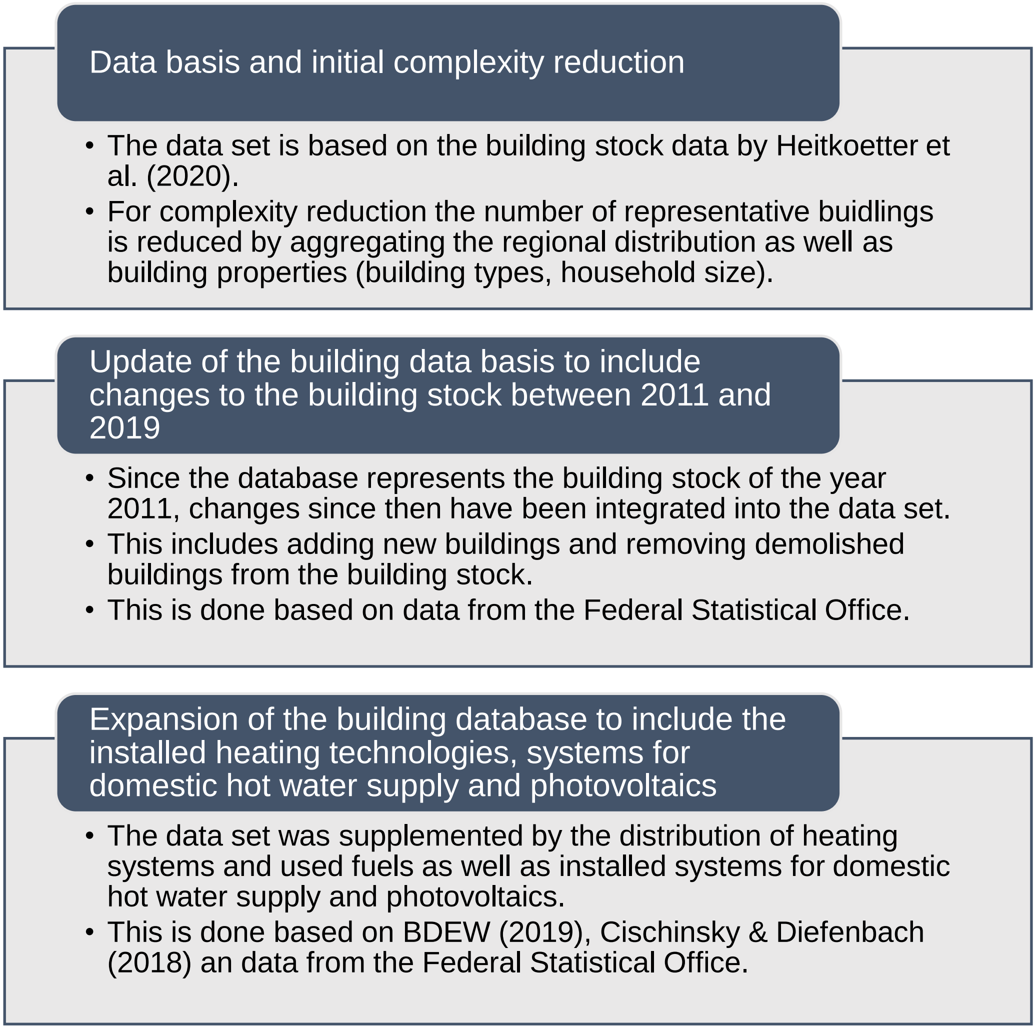

Figure 4: Breakdown of the steps of the construction of the data set.

Own illustration.

Data basis

As the basis for the current building stock including installed systems, the data set provided by Heitkoetter et al. (2020) is used. The authors provide a data set, which includes a regionalized definition of representative buildings in Germany for the building stock of the year 2011. The data set is based on regionalised and detailed data from the 2011 census (Zensus (2011)). The original data set consists of 729 different representative building definitions. The representative buildings are characterized by the following categories (the different specifications of the categories in brackets)[3]:

[3] An overview over all used categories and specifications can be found in sheet C1 of the data repository.

- heating type (single storey heating (and other heating types); central heating; district heating)
- flat area (<60m^2; 60-99m^2; >99 m^2)
- household size (1; 2; >2)
- number of flats (1; 2-6; >6)
- building type (detached; row; semi-detached)
- year of construction (<1979; 1979-2000; 2000-2011)

For each of the defined buildings additional data is given:

- number of buildings per district (distinguishing 402 German districts)
- average flat area [m^2]
- absolut heat demand weighted according to number of residents [kWh]
- absolut heat demand for domestic hot water [kWh]
- average number of residents per flat

Reduction of the number of representative households:

Since the aim of the data processing is to use the representative households as model input, an important focus of the analysis is the trade-off between accuracy and manageability of the number of building types. For this reason the number of unique representative buildings was reduced. It was examined which reductions could be assumed to be acceptable with regard to the informative value of the data. In the course of this, three measures were identified:

- Aggregation of the 402 districts and the corresponding building data to 15 climate zones. These were defined according to the VDI 4655 (2019) guideline.
- Reduction of the specifications within the category "household size" from 3 specifications (1 person; 2 persons; more than 2 persons) to 2 specifications (1-2 persons; more than 2 persons). To do this, we calculated the corresponding average number of residents per flat for these new category specifications based on the data on household size from Heitkoetter et al. (2020).
- Elimination of the distinction between "building types" using the average heat demand per building as given in Heitkoetter et al. (2020).

Update of the database to include changes to the building stock between 2011 and 2019:

Since the data set refers to the building stock of the year 2011, we have updated it to reflect the building stock of the year 2019. The updating of the data is divided into two steps: The addition of buildings to the building stock that were newly built in the period 2012-2019 and the reduction of the number of buildings according to the demolition during that period.

1. Addition of new buildings

The number of new buildings and flats built in the period 2012-2019 and the increase in living space are based on different data sets by Destatis (more information in the data repository). The distribution of those buildings to the “number of flats” category were drawn from Destatis (2019a). As an assumption for the average flat area of new build buildings depending on the “flat area” category and the “number of flats” category, the data of Zensus (2011) was evaluated with regard to buildings constructed after 2009. The distribution of the buildings regarding the “heating type” category was based on Destatis (2019b). It was assumed that the average number of flats for each “number of flats” category as well as the assumptions for demand of hot water do not differ from the assumptions of the existing data set by Heitkoetter et al. (2020). Based on these assumptions, the new buildings for the years 2012-2019 were defined and distributed among the categories in such a way that all known correlations described are complied with. For the new buildings it is assumed, based on the monitoring reports of the KfW program “energy efficient building” (Diefenbach et al. (2014a), Diefenbach et al. (2014b), Diefenbach et al. (2015), Diefenbach et al. (2016), Diefenbach et al. (2018a), Diefenbach et al. (2018b)) and Loga (2002), that they have a specific heating demand of 55 kWh/m^2. For an overview of the results and the assumptions relating to the new buildings as well as a detailed derivation of the value for their specific heating demand please refer to the sheet C2 of the data repository.

2. Demolition of buildings

The overall number of demolished buildings and flats as well as the corresponding flat area is based on Destatis (2019c). The distribution of demolished buildings to the "construction year" category and the “number of flats” category is based on the annual reports Destatis (2013), Destatis (2014), Destatis (2015), Destatis (2016), Destatis (2017), Destatis (2018) and Destatis (21019d). The definitions of the “construction year” classes in these reports differ from those of the present data set. It is therefore assumed that the demolition within the classes is distributed evenly over the construction years. No information is available on the distribution of demolished buildings with regard to the categories "household size" and "heating type". A uniform distribution is assumed here. Based on the identified data on demolition of residential buildings, the number of demolished buildings is distributed among the representative building types. For an overview of the results please refer to the sheet C3 of the data repository.

Expansion of the building database to include the installed heating technologies

Based on BDEW (2019), the data on the German building stock was supplemented by the distribution of electric heating systems and/or used fuels. In BDEW (2019), the shares of heating systems in the total number of residential buildings is given. Using additional data from Destatis (2019c) on the distribution of buildings in single and multi-family houses the distribution of heating systems in the building stock can be estimated depending on the specifications of the “number of flats” category and the “heating type” category. To the best of our knowledge no information is available on the dependency between the heating system installed and the “construction year”, “flat area” and “household size”. A uniform distribution is assumed here. The validation of the results shows that the share of heating systems based on the number of buildings as well as based on the number of flats from BDEW (2019) can nevertheless be approximated well. In data sheet C4 of the data repository you find these distribution results as well as further assumptions.

Expansion of the building database to include installed systems for domestic hot water supply

The distribution of domestic hot water supply technologies to the representative buildings is based on two sources. In BDEW (2019), the shares of the various systems in the building and housing stock in 2019 are shown depending on the “heating type” and the installed heating technology. Data from Cischinsky & Diefenbach (2018) was used to make rough estimates of how these technologies are distributed between the categories "construction year" and "number of flats". Neither of the two sources allows statements on the dependence of hot water supply on the “flat area” or “household size”. The heating systems were distributed among the building stock in a way that the correlations known from the sources are fulfilled. For a detailed description of the result of the distribution, please refer to the data sheet C5 of the data repository. BDEW (2019) states that in approx. 77% of flats with solar thermal systems, these are additionally used for space heating. The representative buildings with solar thermal systems are divided up accordingly.

Expansion of the building database to include installed photovoltaic systems

Based on Cischinsky & Diefenbach (2018), for each representative building, depending on the categories “construction year”, “number of flats”, “fuel / heating system” and “hot water technology”, it is estimated what percentage of the buildings is equipped with a photovoltaic system. For a detailed description of the result of the distribution and underlying assumptions, please refer to the data sheet C6 of the data repository.

Discussion of data quality and final remarks

When using the dataset one should keep in mind that this version can only provide an approximation of the German building stock. Though the individual data sources are of high quality, the combination can result in slight missmatches and can therefore only be used as an approximation. This has several reasons. First, various assumptions were made. Although the individual data sources contain information, for example, on the share of specific heating systems in the building stock, they do not contain information on the specific distribution of this share along all defined building characteristics such as year of construction or household size. Therefore, for example, the assumption of a uniform distribution was made at various points. In other cases, distributions were calibrated manually to reproduce information from the data sources as close as possible. Of course, these manual calibrations may not always reflect the real circumstances. Also when updating the data for the year 2019, changes in the state of insulation of the existing houses were not considered. Despite these limitations, the data set can be seen as a good approximation to the real building stock and the installed systems. The final result is the database of representative households for the German building stock 2019 can be found in the data sheet C7 of the data repository. Here, not only the numbers of the individual representative buildings are listed, but also the respective heating, hot water and electricity demands. The latter is calculated according to the methods of VDI 4655 (2019).

3 Data for supply-side related modeling

3.1 Capacity bookings in the European gas transmission system

Motivation

Financing of gas networks in the EU occurs via the entry-exit regime. The entry-exit system requires network users to book entry and exit capacities in explicit auctions whenever transporting gas into or out of a certain market area, paying the corresponding tariffs. Capacity can be booked hourly, daily, weekly, monthly, quarterly or yearly. Products for each duration have different pricing per unit volume of gas, where short-term bookings tend to be generally more expensive. To analyse the impact of the temporal capacity pricing structure in a realistic setting, using the European Gas market model TIGER (Lochner (2012)), it is relevant to incorporate historical capacity bookings. Figure 5 illustrates the procedure of data extraction, data processing and database creation.

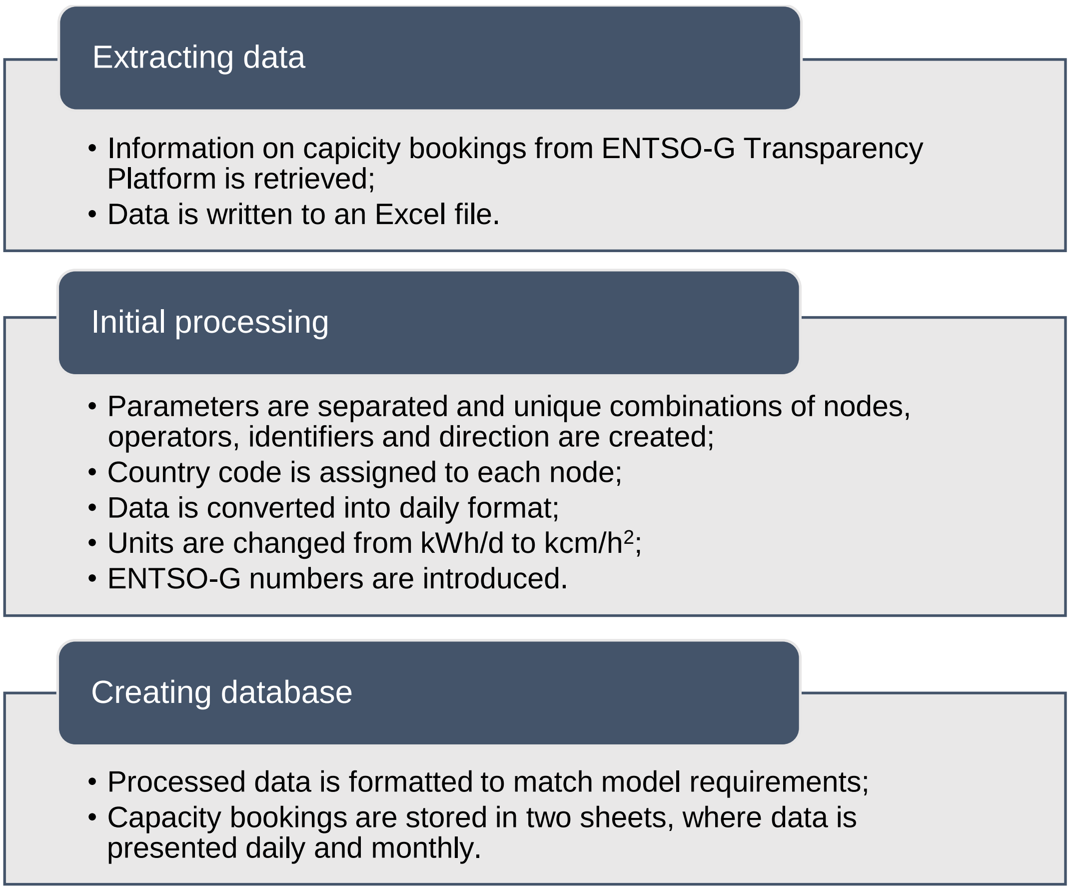

Figure 5: Breakdown of automatic processing using python.

Own illustration.

Data

Information on historical capacity bookings can be obtained from ENTSO-G Transparency platform (2020). European Network of Transmission System Operators for Gas or ENTSO-G (2009) facilitates and enhances cooperation between national gas transmission system operators across Europe. One of the key tasks of the association is to provide regular information on gas supply and demand for the European market, which includes capacity bookings.

Parameters stored in the database

Table 2 specifies the parameters chosen to fully describe the pipeline system for capacity bookings.

Table 2: Parameters to describe the pipeline system for capacity bookings.

Country	Represents the domicile of the operator, where capacity is ordered
Node Name	Describes points, where the gas flow is measured, and data is taken.
Operator	Offers gas delivery capacity in all directions to end user markets.
Identifier	The Energy Identification Code or EIC, which uniquely identifies entities and objects related to the electricity and gas sector
Direction	Describes the direction of gas flow at each node
Entsog Number	Identity numbers for cross-border nodes. Obtained from Transmission Capacity Map (2019)

Processing the data

Historical capacity bookings are collected from ENTSO-G Transparency platform and are processed via python scripts. A detailed description of the Python script as well as the Python Code itself can be found under the DOI https://doi.org/10.5281/zenodo.4420042 (Zip-File: "PythonCodeToProcessCapacityBookings.zip"). Data containing the processed historical capacity bookings per entry and exit point accumulated on a daily basis can be found in the data sheet D1 of the data repository. Proccessd data on a monthly basis can be found in the data sheet D2.

3.2 Database for gas infrastructure modeling and assumptions on gas market uncertainties

Motivation and used model

Work package three (WP3) aims to investigate the long-term supply considering gas market uncertainties. In the context of energy transition, the role of natural gas in the power and heating sector is uncertain, as was already discussed in Section 2.1. Furthermore, the Russian-Ukraine dispute pose the question, whether the Ukraine gas transit route will be available after 2020. Finally, global efforts in phasing out carbon-intensive fuels, in particular coal, increase the demand for LNG and this leads to uncertain LNG price levels for upcoming decades. In order to cover these uncertainties in gas market models, we propose a stochastic optimization approach, based ond the Gas Market Model GAMAMOD-EU (cf. Hüttenrauch et al. (2018)). Within the Erdgas-BRidGE project, the model data have been updated and calibrated according to the base year 2015. The database includes data about gas demand assumptions and LNG capacities (data sheet E1 of the data repository), production capacities (data sheet E2 of the data repository) and production costs (data sheet E3 of the data repository), demand load profiles (data sheet E4 of the data repository), storage capacities (data sheet E5 of the data repository) and transport capacities (data sheet E6 of the data repository). Furthermore, GAMAMOD-EU is extended to an investment model. For that reason, data and assumptions on investment in gas infrastructure have been collected and prepared for the model. A special focus was placed on elaborating data for infrastructure investment and data to cover future uncertainties in the model. The applied methodologies and assumptions are discussed in the following section in details.

Data base for gas infrastructure

Pipelines - There are at least two approaches for considering pipeline extensions in gas market models. The first option is to consider discrete pipeline projects and the decision whether they will be built or not. From this approach the problem arises that there exists only limited data on concrete pipeline projects, in particular in the long term. Furthermore, this approach has to be modelled as a mixed integer problem (yes/no decision for building a pipeline in the model) that leads to more complex solution algorithms as in linear models. The second option is to consider a maximum of aggregated pipeline extension capacities between countries and applying the assumption of a continuous extension of these pipeline capacities. This assumption enables a linear modeling approach. In this project, we follow the latter approach. We

assume both, new pipeline connections between EU-28 countries as well as the extension of existing gas transport connections.
The pipeline extension capacities refer to the list of projects of common interests (PCI) for complete new gas transit routes. Furthermore, we assume that existing connections among the EU-28 Member States can be extended by a maximum of 50% of their existing capacity. Finally, we exclude the extension of connections, e.g. transit routes from Russia to Europe via Belarus. The resulting list of pipeline extensions can be found in the data sheet E6.
Using the continuous extension approach, the model needs a relative cost extension factor in EUR/GWh/Tkm that considers costs (EUR) in relation to the capacity (GWh) and the distance (km). Referring to Lochner (2012), we assume 15.42 EUR/GWh/Tkm.

LNG - We assume LNG extension capacities for existing and new LNG importing countries. The potential refers to the GIE (2020). Similar to pipeline extensions, we do not assume the realization of a single project, but the continuous extension of LNG import capacities. Hence, the costs are broken down to unit costs in EUR for importing one GWh LNG per annum. The resulting list of potential LNG expansion capacities per EU-28 Member state can be found in the provided data sheet E1. We assume expansion costs with reference to Lochner (2012) about 12,671 EUR/GWh/a.

Gas storages - In the model we distinguish among four kind of gas storages, depleted gas fields (s1), aquifer (s2), fields (not depleted, s3), salt caverns (s4). All four types of gas storages have different technical characteristics, in particular injection and withdrawal rates. Furthermore, the availability and, hence, the potential for gas storage expansions differ among the EU-28 Member States. Data sheet E5 of the repository proves the potentials.

Uncertainties in future gas markets - assumptions on the scenario tree
In order to deal with gas market uncertainties, a stochastic programming approach is implemented in GAMAMOD-EU. The data set for the considered uncertainties cover demand uncertainties, LNG price uncertainties and uncertainties about the availability of the Russian-Ukraine transit after 2020. The data collection approach of the European natural gas demand is based on the dissertation of Eser (2019). The forecasted data is orientated on the “Slow Progression” scenario of ENTSO-G (2017). The overall gas demand is expected to be stable in this scenario and based on that, we developed gas demand uncertainties following the process in Figure 6.

In our analyses, we select the Slow Progression Scenario with a stable gas demand as our baseline for the further development of the gas demand in the EU-28 Member States. The scenario's data cover only the period up to the year 2030. For that reason, we continue the development by ourselves until the year 2045. In doing so, we first determined the percentage differences in demand between the years 2017 and 2030. Assuming that the development of demand remains the same per year, the values of 2045 are calculated. The natural gas demand for the EU-28 and for other remaining European countries are determined based on the forecasted data. In order to cover uncertain gas demand developments, we create three scenarios that assume an deviation from our base line demand, namely, an upward deviation of 10%, a stable trend (0%) and a downward deviation of -10% in 2030 and 2045. Furthermore, the scnearios are considerd as stable trends. Hence, an increased gas demand in 2030 will further increase up to 2045, and vice versa. We end up with three scenarios while all scenarios have the same probability.The resulting demand for all scenarios in 2030 and 2045 is listed in the sheet E1 of the associated repository.

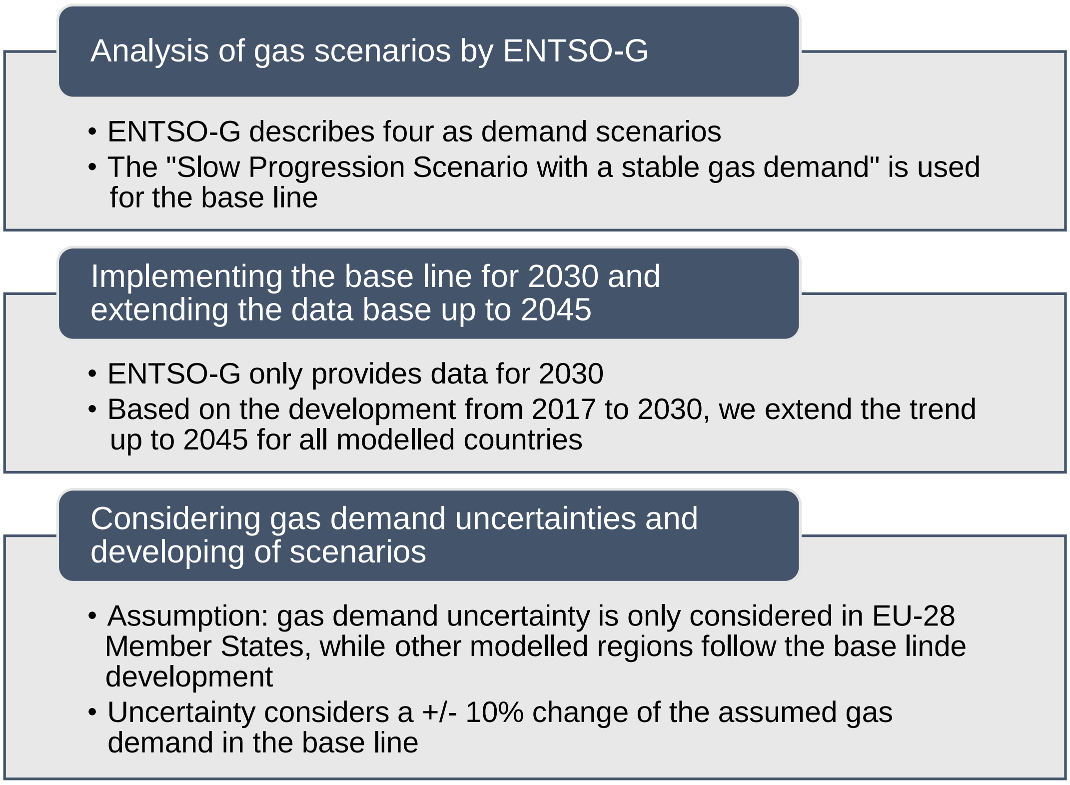

Figure 6: Process for developing gas market scenarios.

Source: Own illustration.

LNG prices depend on global gas markets. For example, an increased Asian gas demand leads to higher LNG prices in Europe, as LNG suppliers are able to react flexibly according to the demand. In order to cover this aspect in a European gas market model, we consider a high and a stable LNG price scenario, using a mark up for LNG imports in the model. Using historical freight prices, we assume a markup of 20% in the high price scenario.

Contracts for gas supply through the Ukraine are going to expire by the end of 2020 and further gas transits through the Ukraine are uncertain. Following Egging et al. 2016 we assume a 50% chance for a gas transit after 2020. The combination of uncertainties results in a scenario tree with twelve scenarios that are equal likely. Figure 7 shows the scenario tree. These scenarios are the base for the analysis that are provided in Hauser (2020).

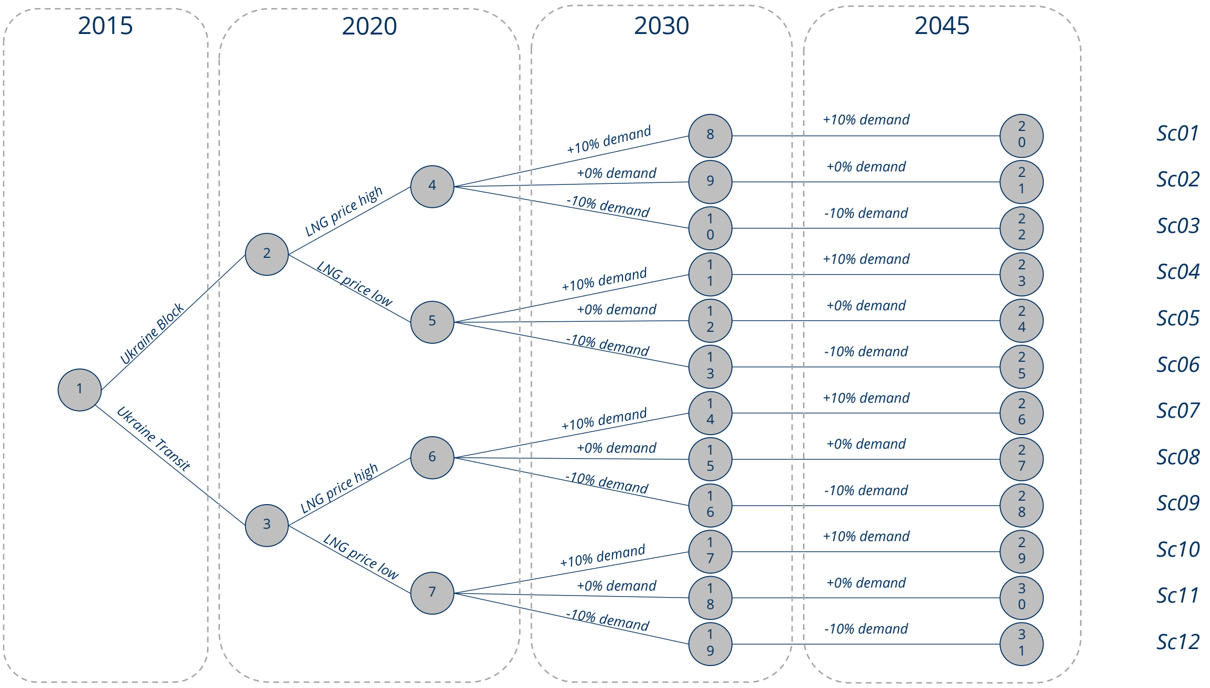

Figure 7: Scenario tree.

Own illustration.

Discussion

Modeling uncertainties include probability estimations for single scenarios. For short-term uncertainties, probabilites cause by historic observations, e.g. the fluctuation of gs demand in correlation with temperatures. For a long-term perspective, it is much more difficutl to derivate reliable probabilites for single uncertain events, e.g. a stop of the Ukraine tranist. A pragmatic way to deal with this circumstance is to estimate equal distrubution of the probability. Against this backdrop, this chapter provides an initial approach to create a scenario tree for long-term uncertainties. Results of a stochhastic optimizazion should always include the aspect of estimated probabiities and the impact on the results.

4 Final remarks and outlook

The objective of this data documentation and the associated data repository is to contribute to transparency of data that are used in public funded projects in the field of energy system analysis. In particular, within this documentation we provide data which has been processed within the research project Erdgas-BRidGE (FKZ: 03ET4055A and 03ET4055B). Thereby, the power, the building and the gas sectors are covered. The documentation focuses mostly on data that are required for modeling scenarios for the next decades. However, most sources include historic data and are also useful for modeling of the past. The prsented data are the base to answer a row of reseach question that are adressed in presentations and publications. Within the Erdgas-BRidGE research project, the following papers are published or are under preparation:

- Arnold, Fabian; Czock, Berit; Frings, Cordelia: Modeling investment decisions of households in energy technologies: The case for efficient CO_2 pricing (working titel), in progress.
- Çam, Eren; Lencz, Dominic: Pricing short-term gas transmission capacity: A theoretical approach to understand the diverse effects of the multiplier system. EWI Working Paper 02/20. Available at https://www.ewi.uni-koeln.de/cms/wp-content/uploads/2020/08/EWI_WP_20-02_Pricing_short-term_gas_transmission_capacity_Cam_Lencz.pdf.
- Haumeier, Julian; Hauser, Philipp.; Hobbie, Hannes; Möst, Dominik (2020): Grünes Gas für die Gaswirtschaft – Regionale Power-to-Gas-Potentiale aus Onshore-Windenergie in Deutschland, Zeitschrift für Energiewirtschaft, 44(2), 61-83 2020.
- Hauser (2020). Does More Equal Better? Analyzing the Impact of Diversification Strategies on Infrastructure in the European Gas Market (submitted).
- Scharf, Hendrik; Arnold, Fabian; Lencz, Dominic (2021): Future natural gas consumption in the context of decarbonization - A meta-analysis of scenarios modeling the German energy system, Energy Strategy Reviews, 33(1), 100591 2021.
- Scharf, Hendrik; Möst, Dominik: Implementing district heating into electricity market models - overview and analysis of different detail degrees by means of the German power sector, in progress.
- Scharf, Hendrik: Future role of natural gas in the power sector (working title), in progress.

Furthermore, the following conference talks have been contributed so far:

- Hauser, Philipp: Evaluating Security of Supply in the European Natural Gas Market - A Stochastic Programming Approach, Conference on Computational Management Science, Trondheim, 29th to 31st of May, 2018.
- Hauser, Philipp; Schmidt, Matthew; Möst, Dominik: Challenges in the European natural gas market: Parsing the value and costs of supply diversification, iSEnEC – Integration of Sustainable Energy Expo & Conference, Nuremberg, 17th to 18th of July, 2018.
- Çam, Eren; Lencz, Dominic: Pricing short-term gas transmission capacity, Enerday, Dresden, 12th of April 2019.
- Scharf, Hendrik; Arnold, Fabian; Lencz, Dominik: Drivers and barriers of future gas demand - A meta analysis, Enerday, Dresden, 12th of April 2019.
- Çam, Eren; Lencz, Dominic: Financing the gas transmission network, International Conference on The Economics of Natural Gas 2019, Université Paris-Dauphine, 21st of June, 2019.
- Çam, Eren; Lencz, Dominic: Pricing of gas transmission capacity, International Congress on Industrial and Applied Mathematics (ICIAM) 2019, Valencia, 15th to 19th of July, 2019.
- Hauser, Philipp: A modeling approach for the German gas grid using spatial, temporal, and sectoral highly resolved data (GAMAMOD-DE), International Congress for Industrial and Applied Mathematics, Valencia, 14th to 19th of July, 2019.
- Hauser, Philipp: Infrastructure expansion in the European natural gas market considering uncertain gas demand, OR, Dresden, 3rd to 5th of September, 2019.
- Arnold, Fabian; Czock, Berit; Frings, Cordelia: Bottom-up modeling of heating investment using clustered time series data, Enerday, Dresden, 12th of April 2019.
- Hauser, Philipp: The Contribution of Gas Infrastructure to Security of Gas Supply in Europe – A Stochastic Programming Approach, International Ruhr Energy Conference (INREC), Essen, Germany 9-10, September 2020 (online).

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