Key Factors for scenario generation for energy systems

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Abstract:

For scenario generation, methods like Delphi and cross-impact analysis are utilized. A key requirement for these methods is the determination of relevant key factors for scenario generation and the subsequent specification of ranges for each key factor. Thereby the determination of relevant key factors is subject to the selected method and the researcher responsible for implementing the method. In this paper, a metastudy of seven influential energy and climate policy scenarios is carried out and a set of key factors for energy system scenario generation derived. The resulting collection of key factors is visualized in a *shell model*, which is designed to reduce the probability of omitting key factors for scenario development. Hereby, the derived key factors are clustered in four shells to provide a readable and clear check list for scenario generation. The shell model is designed to provide guideline for both qualitative and quantitative scenario generation. With the hierarchical structure of the key factors creating storylines starting with context factors as well as building energy models starting with the power system is possible. Furthermore, the ranges of exemplary key factors are determined, visualized in boxplots, to provide a quantitative guideline for the scenario generation.

Keywords: IEWT 2019, Energiepolitik, Szenarienanalyse, Metastudie

1 Introduction

Energy and climate policy scenarios provide important policy advice to key players in the energy system. The qualitative and quantitative definition of scenarios, used to forecast and model possible energy system futures, therefore has an indirect yet strong impact on decisions affecting the design and operation of power systems. Qualitative scenarios are used to raise understanding and awareness in the population, while quantitative scenarios are basis for planning and operating ([1], [2]). Scenario generation is a creative process, where methods are required to make the process transparent. A variety of methods such as the cross-impact analysis and the Delphi method (see chapter 3) are used for scenario generation. The first important step for scenario generation is the identification of key model parameters (e.g. no. of electric vehicles in the system) (in the following key factors), used to describe (qualitatively and quantitatively) the desired scenario. The key factor selection

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method, the responsible researcher and the type of energy system model at hand influence which key factors are considered during scenario generation. In the course of this process, a certain degree of subjectivity is unavoidable, baring the danger of omitting important key factors, which can have a strong impact on the results delivered by the energy system model.

In this paper, a metastudy of seven influential energy and climate policy studies is carried out for Germany and the key factors used to describe the energy system in these scenarios are derived. Hereby mainly current studies authored by different institutes commissioned by a variety of ministries build the basis for the analysis. The identified key factors are then condensed, clustered and visualized in a *shell model* which can be used as a guideline for selecting key factors in the process of scenario generation. The shell model supports qualitative storytelling and the quantitative scenario definition by providing a hierarchical guideline for classifying and categorising key factors for a consistent scenario generation. Hereby the shell model is a supplement to classical methods such as cross-impact analysis and Delphi. As a second outcome of this paper, the typical ranges of exemplary key factors for the quantitative perspective are determined and discussed.

This paper is organized as follows: In Section 2, the selected studies/scenarios are introduced. In Section 3, scenario perspectives are presented, followed by common methods for scenario generation such as cross-impact analysis and Delphi in Section 4. In Section 5, the shell model is explained. Section 6 shows the ranges for exemplary key factors, followed by a conclusion in Section 7.

2 Study Selection

The metastudy is based on seven energy and climate policy studies containing a total of 17 scenarios (six trend/base/reference scenarios, six target scenarios with 80 % and five with 95 % emission reduction with respect to 1990). The selection is based on the following criteria: actuality of the study, scope and variety of energy system models and an extensive documentation. The selected studies are shown in Table 1. The focus of these studies lies on Germany. All scenarios show results until 2050.

Table 1: Selected studies

Title	Contracting Authority	Employer	Authors	Year
Entwicklung der Energiemärkte – Energiereferenzprognose [3]	ERP	BMWi	Prognos, EWI, GWS	2014
Klimaschutzszenario 2050 [4]	KSZ	BMUB	Fraunhofer-ISI, Öko-Institut e.V.	2015
EU Reference Scenario 2016 EU	EU	EU	European	2016

Energy, transport and GHG emissions – Trends to 2050 [5]			Commission	
Langfristszenarien für die Transformation des Energie-systems in Deutschland [6]	LFS	BMUB	Consentec, Fraunhofer ISI, IFEU	2017
Den Weg zu einem treibhaus-gasneutralen Deutschland ressourcenschonend gestalten [7]	THG	UBA	IFEU, Fraunhofer IWES, CONSIDEO, Dr. Karl Schoer SSG	2017
Klimapfade für Deutschland [8]	KP	BDI	Boston Consulting Group, Prognos	2018
dena-Leitstudie Integrierte Energiewende [9]	IEW	Dena	dena, EWI	2018

3 Scenario perspectives

There are two possible perspectives for scenarios; quantitative and qualitative. When developing a method for scenario generation both perspectives has to be considered. In the following, therefore the two perspectives are explained briefly. According to [1], the qualitative storyteller describes the possible future in words instead of numbers. Therefore, understanding and awareness in a population about a topic such as climate change and solving strategies can be spread. Another advantage is that soft aspects (which are not possible to put in numbers) can be included. Furthermore, the views of different stakeholders and experts of different fields such as economic and sociology can be represented, so “think-big and interdisciplinary” is possible. On the other hand, quantitative storylines tend to be less transparent then qualitative models and there are not reproducible. Quantitative models express everything in numbers and equations. They provide rigorous internally consistent scenarios, however, the results are more difficult to analyse for the public. Furthermore, due to calculation time, the model is restricted to a certain number of parameters/aspects, so interdisciplinary reflection is limited. To overcome the limitations of both perspectives, there is research done in combining both. One example is the SAS-approach. ([1], [2]) For these mix approaches methods has to be developed which are compatible with both qualitative and quantitative scenarios.

4 Common methods for scenario generation

A common method for scenario generation is the cross-impact analysis. Cross-impact analysis is a forecasting technique that considers the relationship/causal impact between events and the impact of events in history on a certain event in the future. As written in [10] future events are caused by a combination of several antecedent events, which concludes that for forecasting, interrelations between events (also called “cross impact”) need to be considered. A problem of forecasting and scenario analysis based on a list of presumably independent events is that certain events in the mix can impact each other or even be mutually exclusive. To determine the cross impact between events a formalised method was developed: the cross-impact matrix. Events are listed in the rows and the columns; the values in the matrix show the impact (positive, negative, neutral etc.) from one event on the other. Since there is no self-impact, the diagonal is empty. For the cross-impact matrix, the events should be restricted, since there are too many interconnections otherwise. A prerequisite for the effective use of the cross-impact analysis is the selection of relevant key factors. This can be done by consulting expert groups. Two groups of researchers might get different descriptors depending on where their focus is directed (due to restrictions concerning the number of events, it is not possible to select every possible event). Alternatively, existing energy scenarios can be used as a basis for deriving key factors as it is done in this paper /UBK 7819/, [11]

Another model for forecasting is the Delphi method. [12], [11] Delphi relies on a questionnaire answered in several rounds by a group of experts. According to Linstone [12] is “Delphi […] a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem”. Due to the controlled feedback, better results can be achieved than in a face-to-face discussion. The focus lies in the disagreements, which will be analysed and evaluated through the multi-level process with the option to change the own opinion during the process. One weakness of the method, however, is that often only very general statements are reached. The Delphi method can be deployed in several fields, the original and most common one, however, is for forecasting. Delphi is utilized for interdisciplinary groups, where a certain degree of anonymity is required (for example to avoid the bandwagon effect), which work on a complex problem where subjective estimates are necessary. A disadvantages of Delphi is that interrelations between events can hardly be considered. Therefore, a combination with a cross-impact analysis is a common practice. In this way, the advantages of both models can be exploited. As in the case of the cross-impact analysis, the selection of key factors is generally a challenge. Therefore, the next chapter introduces the shell model which visualizes key factors derived from a metastudy and can be used as a guideline for selecting key factors in qualitative and quantitative scenario generation for further use in methods such as Delphi and Cross-impact analysis.

5 Shell model: a guideline for key factor selection

As guideline for the key factor selection a shell model is constructed (see Figure 1). The key factors in the shell model are derived from the metastudy. In a first step, the studies are screened with the goal of identifying key factors which are used to characterize the scenarios in these studies. Hereby, qualitative and quantitative arguments are used, while the degree of quantification is subject to the capabilities of the numerical models used to calculate the scenarios. Key factors are collected, clustered and interdependencies between factors are analyzed. During this process, a hierarchy amongst the key factors is identified and a set of factors is determined which summarizes the key factors used in the analyzed studies. Hereby focus is laid on selectivity of the determined key factors (to avoid sense overlapping). These factors are arranged in a shell model with different hierarchical layers to reflect the hierarchy between factors. The idea of the shell model is to combine two perspectives: the qualitative storyteller with the quantitative modeller. The modeller starts from the centre with the power system (yellow arrow), the storyteller from outside with the context factors to create the story (blue arrow). Depending on the assumed perspective, the scenarios are built either by going from outer to inner shell or vice versa. All key factors on one shell belong to the same level of detail. For better understanding, the number of shells is restricted to four, so not every level of detail is shown. The first shell beginning in the centre is the power system. In a conventional energy system, this is the main part of the energy system. It provides the energy needed in the sectors (security of supply). Historically, the energy system is centred around the power system. This idea gets loosen more and more through e.g. demand side flexibility and prosumer but it still reflects the energy system. The second shell contains first the sector demand and secondly the flexibility which relate to the power system in the sense that it provides balance in supply and demand. The flexibility is split in demand side flexibility and export/import with Europe. The third shell specifies the second shell, splitting the energy demand of the sectors in specific consumption and an index about the necessary amount. Furthermore, the export/import with Europe is specified. The third shell can be split into more and more shells and factors. At the end, the factors can be summarised into four context factors for Germany on the fourth shell, which are in particular: economy, policy, global context and society. The same context factors are true for Europe. For brevity and since there is no focus on Europe the context factors are summarised in European development. Between the fourth and the third shell, there are several measures. These measures do not have a shell for their own; instead, they lay on the border between the two shells. They are links between the shells.

Since the focus of the selected studies lies on Germany, Europe is an exogenous factor in Figure 1, it is not included as total in the scenarios for Germany. This separation from Europe – considering the joint electricity market - can cause problems since Germany influences Europe and vice versa. An extensive electrification in Germany alone has a totally different impact then a joint European electrification. Therefore, a joint view also in the shell model should be considered. Instead of modelling Germany with an interconnection to Europe, the key factors are considered for Europe. Therefore, the part of the shell model in Figure 1 marked in red disappears and Europe instead of Germany is considered in the rest.

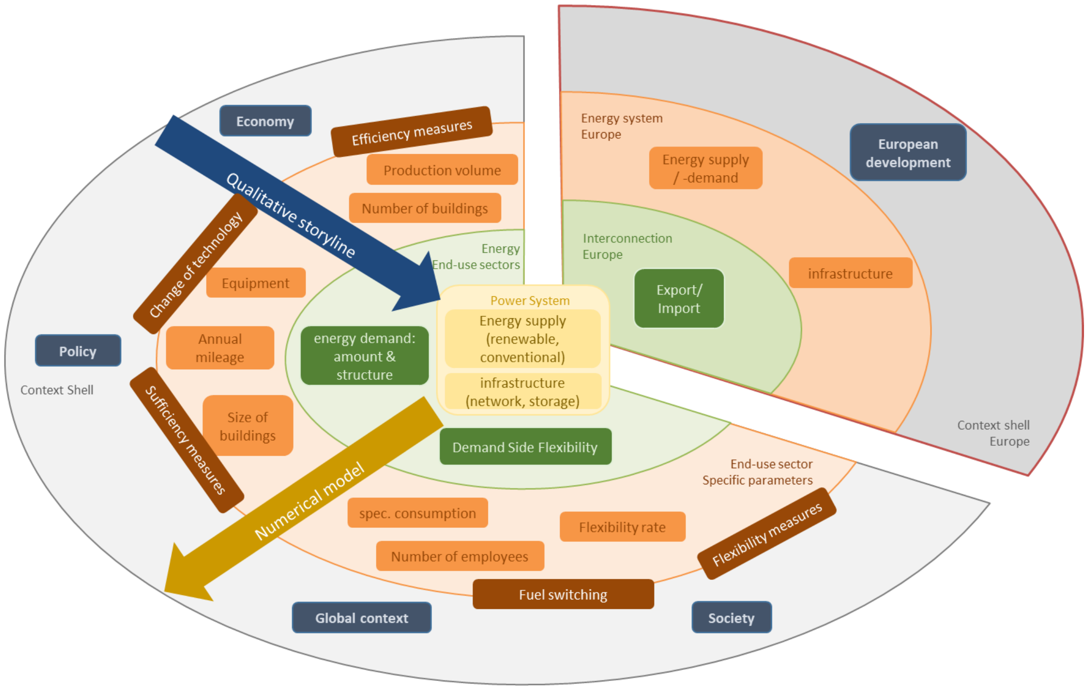

Figure 1: Shell model for the (A) German / (B) European energy system, containing the four shells Power system (yellow), Energy End-use sectors (green), End-use sector - specific parameters (orange) and Context Shell (blue): the storyteller starts from the outside (see blue arrow) with the context factors going in, the modeller starts from the centre (yellow arrow) with the power system going out.

6 Analyses of exemplary key factors ranges, identification of game changers

In this chapter, the assumptions of the studies with respect to the analysed key factors are presented. The following section is structured according to the hierarchy presented in the shell model, starting from the outer shell. First, exemplary context factors are considered. The analysed key factors are population, gross domestic product (GDP), CO_2-price and natural gas price in 2050. After that, the different sectors in Germany are analysed. Here, the second and third shell are combined for the analysis. Housing stock and renovating rate for the residential & tertiary sector, numbers of cars and driving distances for the transport sector and production volume and electrification rate for the industry sector in 2050. The electrification rate of the final energy consumption shows the share of electricity of total energy consumption. For the first shell, the installed net power plant capacity is considered.

6.1 Context Shell

The analysis starts with the context factors. The selected key factors are shown in boxplots in Figure 2. The key factors population and GDP are the same for every scenario in the same study, the development of these key factors is not influenceable with ambitious energy target.

There is little variation for population between the studies. Reason for that is the stable situation in Germany, the only thing that affected the population in the last decades was the migration flows in

2015. Therefore, homogenous assumption regarding population is to expect. An extreme loss of population could result just from extreme evens like war in Europe which would most likely make the climate and energy goals obsolete. For GDP there is greater variation noticeable, but it is still quite homogenous. The highest assumed GDP is in KP (875 $€_{2017}$), the lowest in LFS (613 $€_{2017}$). A very different picture is shown for natural oil price and the CO_2-certificate price. As for population and GDP, the natural oil price is normally the same for all scenarios in one study. Exception is KP. There, two different kinds of scenarios are shown - national solo effort versus global climate protection. For global climate protection, less natural oil is needed which has an impact on the natural oil price (decreased oil price). This is the reason the price there is the lowest with 7 €/GJ. The highest one is at KSZ with 25 €/GJ. The price of KSZ is taken from the annual Energy Outlook 2013. In general, there are great uncertainty regarding the natural oil price, since several factors - as the market power of OPEC and the production of unconventional oil - influence the same. The last graph is the $C0_2$-certificate price. This shows the greatest variation about almost factor 7 from 30 €/t_{C02} to 200 €/$_{tCO2}$. In several target scenarios, the CO_2-price is taken as measure to reach the goals, which illustrates Figure 3. The highest CO_2-prices are found in KSZ-Z95 and KSZ-Z80. On the other hand, in LFS-T, IEW-T and KSZ-T very low CO_2-prices are found. Remarkably are the target scenarios KP-ZG (global climate cooperation), where the CO_2-price is quite low compared to other target scenarios. Reason is that a global cooperation is set which allows global restriction regarding CO_2-emissions and final energy consumption, which makes CO_2-prices less important.

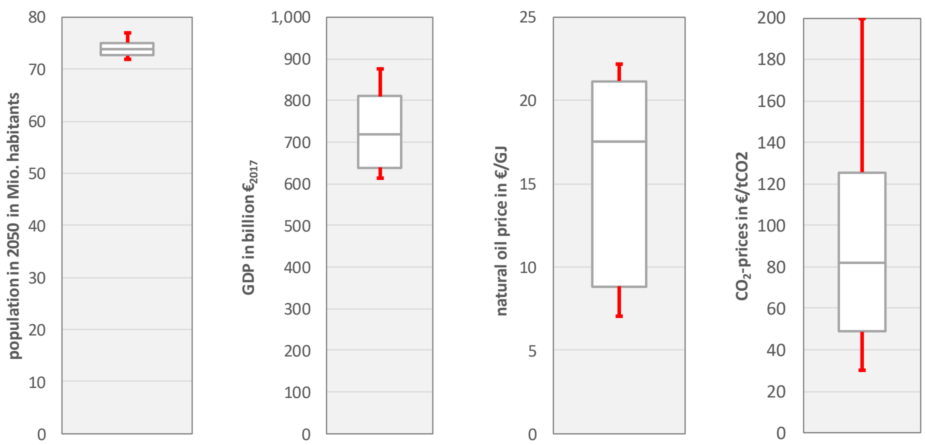

Figure 2: Boxplots for context factors in 2050: population, GDP, natural oil price and CO_2-price

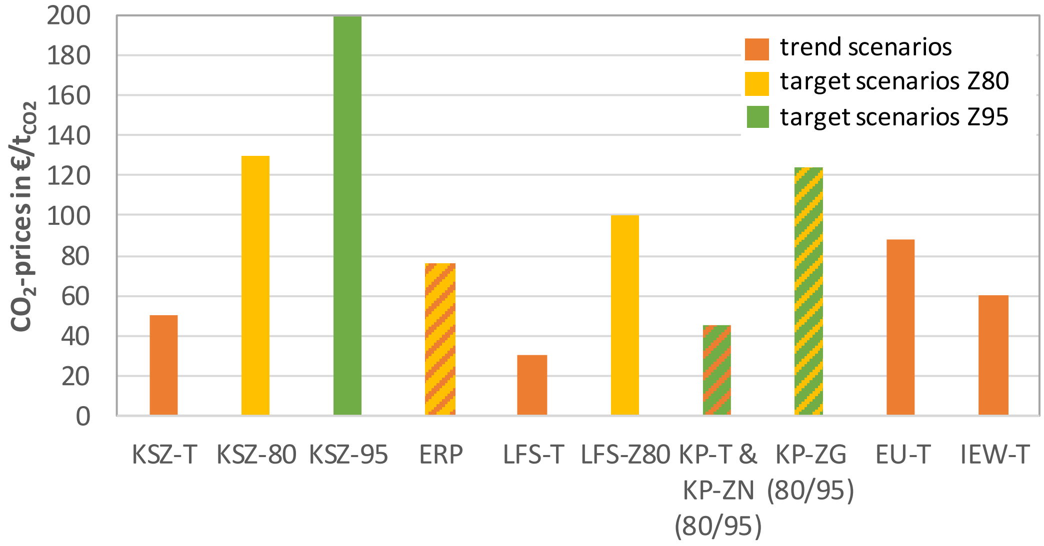

Figure 3: CO_2-prices 2050, red are trend scenarios, yellow target scenarios with 80 % reduction of greenhouse gas emissions in respect to 1990 and green target scenarios with 95 % reduction of greenhouse gas emissions in respect to 1990

To summarise, the prices for natural oil and CO_2 can be adjusted to reach climate and energy goals while population and GDP are less variable and no factor that can be changed from policy/society. Nevertheless, there have influence in most key factors presenting in the next chapter, which shows the importance of these factors for the final energy consumption and greenhouse gas emissions at the end.

6.2 Sectors

In the following the three sector “Residential & Tertiary Sector”, “Transport Sector”, and “Industry Sector” are analysed in detail.

6.2.1 Residential & Tertiary Sector

In the residential & tertiary sector, energy is required for space heating & hot water and devices & processes. The main factor, however, is space heating & hot water, devices & processes just cause a small amount of greenhouse gas emissions in 2015. The energy transition in this sector is hence a thermal energy transition. Therefore, just key factors regarding space heating are selected.

First, the housing stock resp. the specific living area 2050 is analysed. The difference between these two key factors is the population. Since the population is quite homogenous (compare last subsection), just the analyse of one of it is necessary. We chose the housing stock. The housing stock 2050 lies between 3500 billion m² (THG) and 4755 billion m² (LFS) (see Figure 6). Reason why THG is the smallest value is probably that just a target scenario with 95 % greenhouse gas emission reduction is considered so a reduced housing stock foster to reach the goal. The second key factor is the renovating rate. The higher the renovating rate the lower the final energy consumption for space heating and hot water. The renovating rate is widely spread. As expected, the more ambitions are considered the higher the renovating rate gets. Furthermore, there is a trend regarding time: the newer the study the lower the renovating rate since in these studies the focus lies more on technology change than energy reduction. At KSZ-Z95 (the oldest study) a renovating rate of 3.1 %/a is assumed, at KP-T (newest considered study for this key factor) 1.1 %/a is reached in 2050. To compare: today the renovating rate is approx. 1 %. The policy targets a renovating rate of 2 %/a since years now without success. This makes the optimistic renovating rate of KSZ-Z95 not realistic appearing.

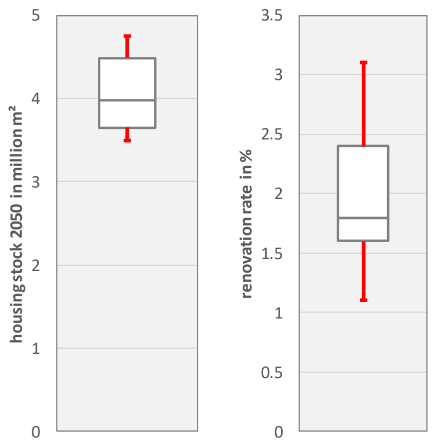

Figure 4: Boxplot for key factors for the residential & tertiary sector in 2050: housing stock and renovating rate

To summarise, the renovating rate can be adjusted to reach climate and energy goals, which is widely utilized in the older target scenarios. Since a practical implementation is not so easy to reach, newer studies focus on technology change instead. The housing stock is less variable.

6.2.2 Transport Sector

In the transport sector, the street-transportation – both passenger cars and street cargo - represent the main part of the transport sector. Therefore, the focus lies on street-transportation, mainly passenger cars due to missing data in street cargo. The annual mileage is one key factor. This factor consists of the amount of vehicles multiply with the driving distance, which are shown in Figure 5. The amount of passenger cars is in most scenarios around 42 million. Only in KSZ-Z95, the amount is decreasing notable (32 million) due to sufficiency measures made in this scenario to fulfil the high climate/energy goals. The driving distances for passenger cars is also quite homogenous with two outliners at both sides. In EU-T the driving distance for passenger cars lies by over 1000 billion pkm, for KSZ-Z95 it is only 730 billion pkm. The notable decrease of KSZ-Z95 is again due to sufficiency measures. The driving distances for road cargo is much more heterogeneous. Reason for that is the dependency mostly to the economy (compare GDP) instead of population, which is also less homogenous than the population. The studies with the smallest GDP (LFS and KSZ) also have the smallest driving distances for road cargo. KP-T, which has the highest GDP, assumes the highest driving distances with 679 billion tkm.

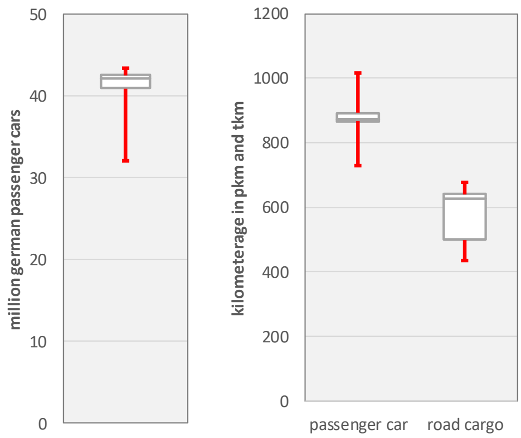

Figure 5: Boxplot for key factors for the transport sector in 2050: amount of passenger cars and driven distances for street transport

To summarise, the amount of passenger cars and driving distances in passenger street transportation are highly depended on the population (and a stable economic situation), which makes it little variable for most scenarios. Sufficiency measure for decreasing the annual mileage in the passenger street transportation is utilized only in one study, where it is used to fulfil ambitious targets. The cargo transportation is much more variable, since the dependency to GDP and economy in general is more difficult to predict. Therefore, more care has to be taken in the cargo transportation part.

6.2.3 Industry Sector

For the industry sector a detailed look at the production volume and the electrification rate is done. The production volumes for different products are shown in Figure 6. As it is seen, the variation of the production volume totally depends on the product. Steel, which has the highest production volume in Germany, also displays the highest variations. The other two production volumes for paper and cement are quite homogenous. One important remark: for this comparison few data are available, which implies that the analysis of this data is problematic. The second considered key factor for the industry sector is the electrification rate resp. electricity demand. The variation between the scenarios are for the most scenarios quite low. Only the electrification scenarios of the IEW show an extreme high electricity demand of over 530 TWh. In general, the IEW-scenarios assume higher final energy consumption which might imply a trend that the newer the study the higher the final energy consumption since the focus lies more on greenhouse gas emission reduction and not on reduction of the final energy consumption.

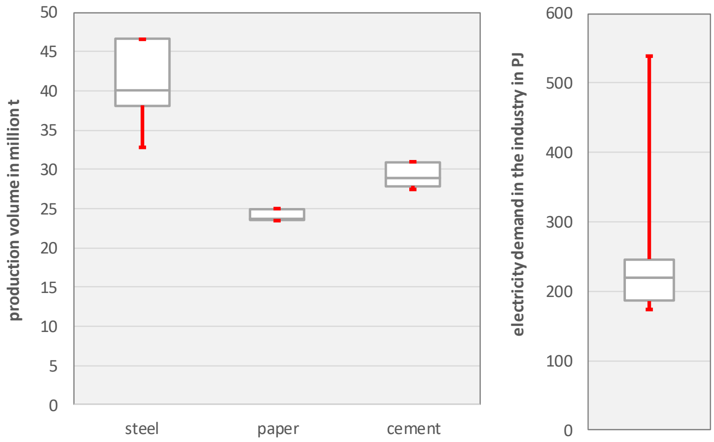

Figure 6: Boxplot for key factors for the industry sector in 2050: production volumes and electricity demand

To summarise, due to a small sample for the production volumes a reliable statement is complicated. For the electrification rate, it is a game changer in the industry which is mostly used I more actual studies.

6.3 Power System

For the power system, the installed net power plant capacity 2050 is considered. The data are split in conventional power plant including biomass for ensured capacity, storage and renewable energies without biomass (see Figure 7). Due to mixing trend and target scenarios the share of conventional and renewable power plants is widely spread. The trend scenarios contain a low rate of volatile renewable energies while the target scenarios reach rates up to >80 % of installed net plant capacity. In total the capacity of power plants increases with increasing rate of volatile renewable energy because the full-load hours for volatile renewable energies like PV and wind is smaller than for conventional coal power plant. An additional interesting fact is that the capacity of storages is limited. Reason for that is on one hand the missing possibility to install more pumped-storage power plants and on the other hand the low profitability of storages. Even in target scenarios, the storage capacity never reaches more than 30 GW (in most target scenarios it stays below 20 GW). Instead, the studies focus on demand-side flexibility and increasing export/import rates.

To summarize, the share of volatile renewable energies in the power system is the main switch lever to reach any climate and energy goals. An increasing storage capacity in target scenarios is noticeable but appears not to become the main way to ensure security of supply.

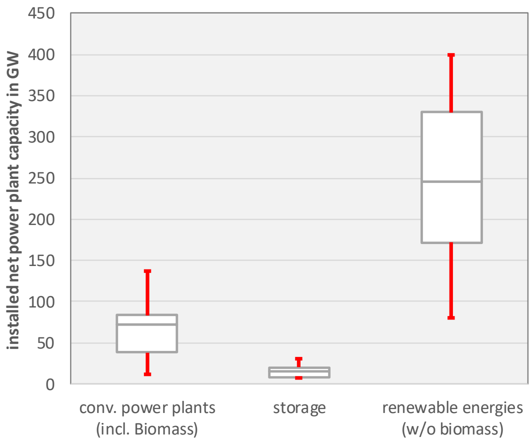

Figure 7: Boxplot for one key factor for the power system in 2050: installed net power plant capacity

7 Discussion & Conclusion

Nowadays, to comply the energy and climate goals in Germany and worldwide the need for scenarios in the energy politics increases. Common methods for scenario generation are Delphi and cross-impact analysis. The key factor selection for theses methods, however, is still an issue. In this paper, a metastudy of seven influential energy and climate policy scenarios is realized to investigate what the main key factors for scenario generation for energy systems are. The key factors are sorted, hierarchical clustered and arranged in a shell model. The shell model works as a guideline for the key factor selection which can used as a supplement to scenario generation methods such as Delphi or cross-impact analysis. Considering the both perspective of qualitative and quantitative scenarios, the shell model can provide aid for both by starting either with the context factors from the outside or the power system from the centre.

Furthermore, similarities and differences for the selected scenarios are analysed with respect to the identified key factor. Ranges of the analysed key factors are determined and visualized in boxplots. As shown in the paper, the variation of key factors is very different. Key factors as the renovation rate or the amount of electricity in the industry differ significantly, while in contrast the population development is very homogenous. The great range for e.g. the renovating rate reflects the uncertainty for the transformation path to 2050. For scenario generation the attention has to focus on these uncertain factors since they influence the future energy system the most. From the boxplots, also ranges for the key factors can be extracted, in this way it can be a quantitative guideline for the scenario generation.

As future work, using the shell model for the scenario generation in the project eXtremOS is planned. eXtremOS is a European project, for scenario generation different European countries have to be considered. The (modified) shell model works for Europe/ European countries, the analysis of the ranges just for Germany. Interesting would be, therefore, a parallel metastudy for other European countries to compare the ranges and to find ranges for a combination of several European countries.

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Literature

[1] Alcamo, Joseph: Chapter six the SAS approach: combining qualitative and quantitative knowledge in environmental scenarios. In: Developments in integrated environmental assessment 02/2008. Amsterdam: Elsevir, 2008.

[2] Trutnevyte, Evelina et al.: Linking a storyline with multiple models: a cross-scale study of the UK power system transition. In: Technological Forecasting and Social Change 89/2014. Amsterdam: Elsevier, 2014.

[3] Schlesinger, Michael; Lindenberger, Dietmar; Lutz, Christian: Entwicklung der Energiemärkte - Energiereferenzprognose - Projekt Nr. 57/12 - Studie im Auftrag des Bundesministeriums für Wirtschaft und Technologie. Berlin: Bundesministerium für Wirtschaft und Technologie (BMWi), 2014.

[4] Klimaschutzszenario 2050 - 1. Modellierungsrunde. Freiburg, Berlin: Öko-Institut e.V., Fraunhofer-Institut für System- und Innovationsforschung (ISI), 2014

[5] Capros, Pantelis et al.: EU Reference Scenario 2016-Energy, transport and GHG emissions Trends to 2050. Athen: Institute of Communication and Computer Systems at the National Technical University of Athens, 2016.

[6] Pfluger, Benjamin et al.: Langfristszenarien für die Transformation des Energiesystems in Deutschland. Karlsruhe: Fraunhofer-Institut für System- und Innovationsforschung (Fraunhofer ISI), 2017.

[7] Günther, Jens et al.: Den Weg zu einem treibhausgasneutralen Deutschland ressourcenschonend gestalten. Berlin: Umweltbundesamt, 2017.

[8] Gebert, Philipp et al.: Klimapfade für Deutschland. München: The Boston Consulting Group (BCG), prognos, 2018.

[9] dena-Leitstudie Integrierte Energiewende - Zwischenfazit Impulse und Erkenntnisse aus dem Studienprozess. Berlin: Deutsche Energie-Agentur GmbH (dena), 2017

[10] Gordon, T. J. et al.: Initial experiments with the cross impact matrix method of forecasting. In: Futures volume 1. Amsterdam: Elsevier, 1968.

[12] Linstone, HA et al.: The Delphi method: Techniques and applications. Portland: State University, 2002.