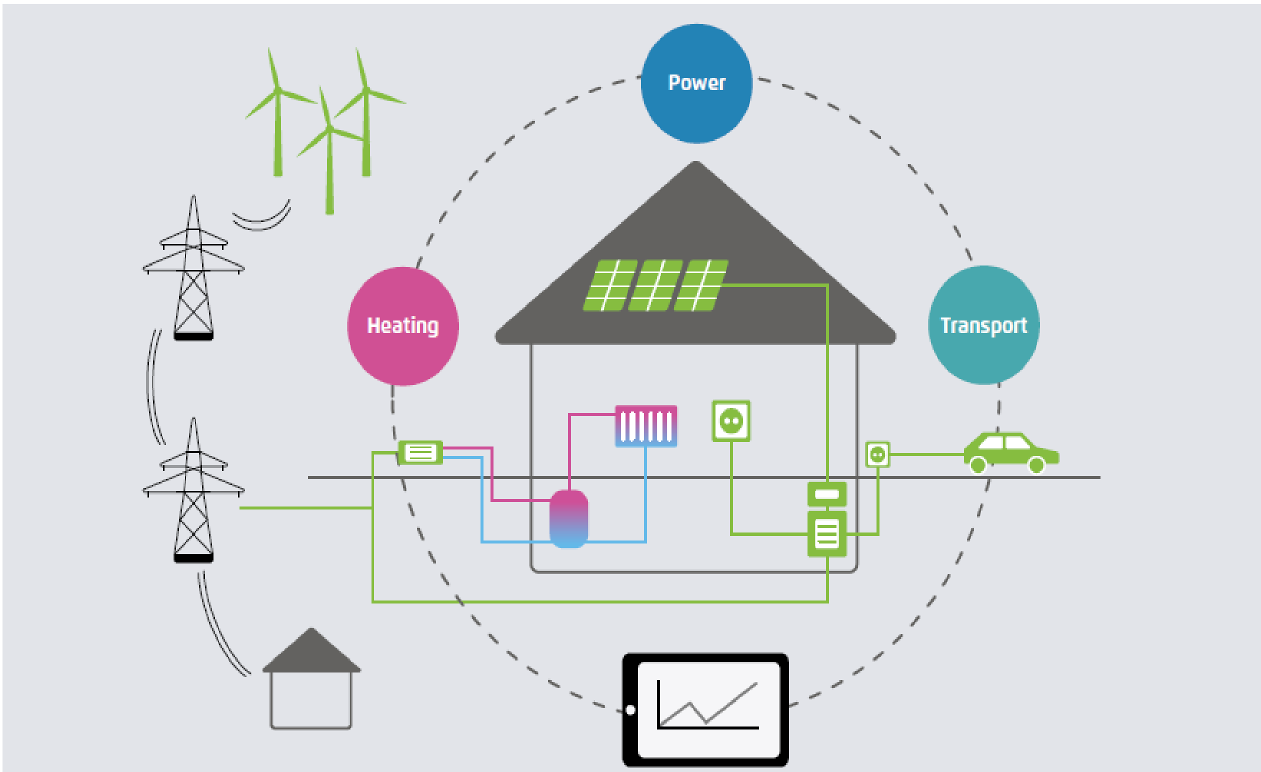
Cross-section excess electricity production integration into heating and transport sectors in Germany for 2030



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Synopsis

AALBORG UNIVERSITY
STUDENT REPORT

Cross-section excess electricity production integration into heating and transport sectors in Germany for 2030

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Program: Sustainable Energy Planning and Management
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Abstract

It is argued that future energy systems will be based on two rapidly developing technologies, wind and solar PV. This situation will demand much more flexibility in the system. Conventional power plants used for backup capacity will be gradually changed with more intelligent, decentralized and fast responding technologies.

This study will try to provide more flexibility in Germans future energy system by integrating excess electricity production from intermittent renewable energy sources into heating and transport sectors. To do that, in total three technologies will be employed. These are heat pumps, thermal storage and electric vehicles.

With EnergyPlan software the reference scenario for 2030 will be designed. Next, on this reference scenario, four new cross-section models with will be added. The generated outputs will be compared between reference and cross-section scenarios mainly based on three parameters: CO2 emissions, total annual costs and critical excess electricity production.

After, in the sensitivity analysis two different cases will be tested. First part will decrease the prices, while the second will increase the capacities for the heat pumps and electric vehicles.

In general, this study will try to prove that cross-section electricity integration approach can have lower costs for the whole energy system, could cut more CO2 emissions, thus help to meet climate goals and finally reduce the surplus electricity production and utilize exported electricity in domestic markets in a cost-effective way.

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Abbreviations

RES - Renewable Energy Sources

EEP - Excess Electricity Production

HP - Heat Pumps

EVs - Electric vehicles

DH - District Heating

CHP - Combined Heat and Power

TS - Thermal Storage

V2G - Vehicle to Grid

G2V - Grid to Vehicle

VRE - Variable Renewable Energy

PP - Power plants

CEEP - Critical Excess Electricity Production

1.0 Introduction

This chapter will introduce to the basics of Germany's energy system and gradually will move to the problem formulation where it will be narrowed down to the research question. Next, in the delimitations sub-chapter, the project will be placed into boundaries. And finally it will be finished with the project structure where every chapter shortly will be described.

Germany's energy system transformation is referred to a concept called *Energiewende*, which literally means energy transition. It is a long-term strategy to meet the outlined goals for climate and energy. The climate goals are to reduce CO2 emissions 40% by 2020, 55% by 2030 and 80-95% by 2050 compared to 1990 level. While the aims for energy sector is to increase renewable energy share in final energy consumption to 18% by 2020, 30% by 2030 and at least 60% by 2050. Furthermore, this transformation includes nuclear power plants phase-out by 2022, and the reduction of primary energy consumption by half in 2050 compared to 2008 figures. These objectives partly illustrate the four main pillars of Energiewende: CO2 emissions reduction, increased energy security, nuclear power decommission and the guarantee the competitiveness and growth for the industry (Agora Energiewende, 2015 (a)).

Basically Energiewende resembles the transition from the energy generation based on fossil fuel to the energy production which increasingly relies on intermittent renewable energy sources (RES). It means gradual phased out of coal and nuclear power plants from energy system and installing more capacity of RES technologies, mainly solar PV and wind power.

In order to have a brief look into how the Germany's energy system looks like, the total energy consumption is a good place to start (Figure 1). In fact, Germany is the largest user of energy in the EU, responsible for around 20% of total energy consumption (Irena, 2015).

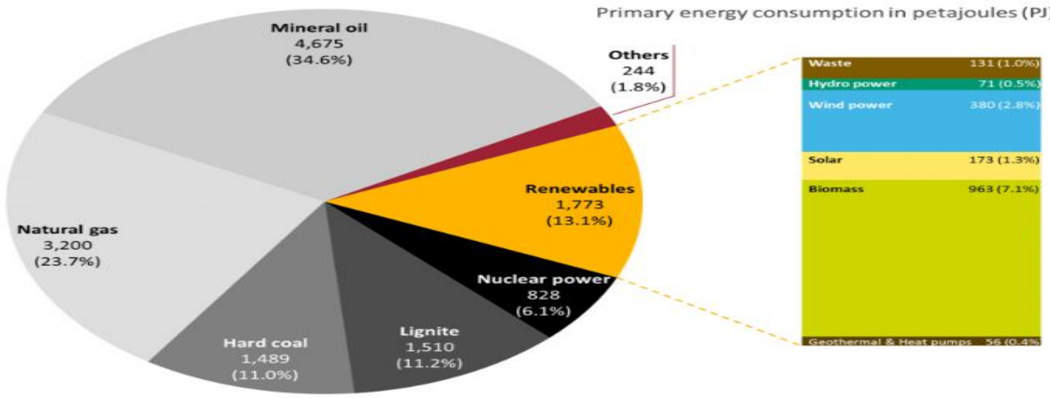


Figure 1: Germany's Energy mix 2017: Energy sources share in primary energy consumption

It can be seen from the figure above that the fossil fuels are the dominant energy source (AG Energiebilanzen, 2017). The biggest share takes oil, followed by natural gas, coal (hard coal and lignite), RES and nuclear power. Biomass has the highest share in the renewable sector.

When it comes to the final energy consumption by sectors, the most energy is used in buildings, around half of all energy. While the transport and industry sectors share the rest of energy consumption in almost equal parts (Irena, 2015).

This project will give a strong emphasis on sector integration. Therefore, it is relevant to introduce electricity, heat and transport segments separately.

1.1 Electricity sector

Since the introduction of feed-in-tariff scheme in 2000, the renewable share started to climb while other fuels like coal, lignite and oil started to decline (Figure 2). Currently RE share in gross electricity consumption is around 30% and constantly growing (Irena, 2015)

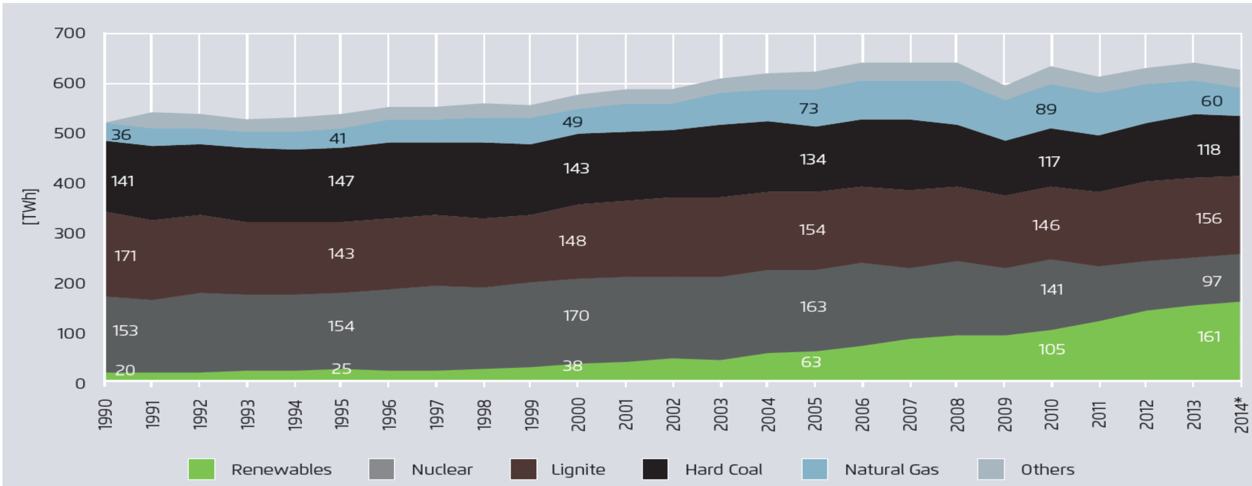


Figure 2: Structure of gross electricity generation in Germany

Most of the renewable energy in 2015 was generated by wind turbines, followed by biomass, photovoltaic's and hydropower sources (Agora Energiewende, 2015 (b)).

1.2 Heat sector

Heat sector has the biggest demand for energy in Germany. Natural gas dominates in this sector, especially is true for building where gas-fired boilers takes the biggest share (Agora Energiewende, 2017). Despite the fossil fuel dominance, RES started to grow as well (Figure 3).

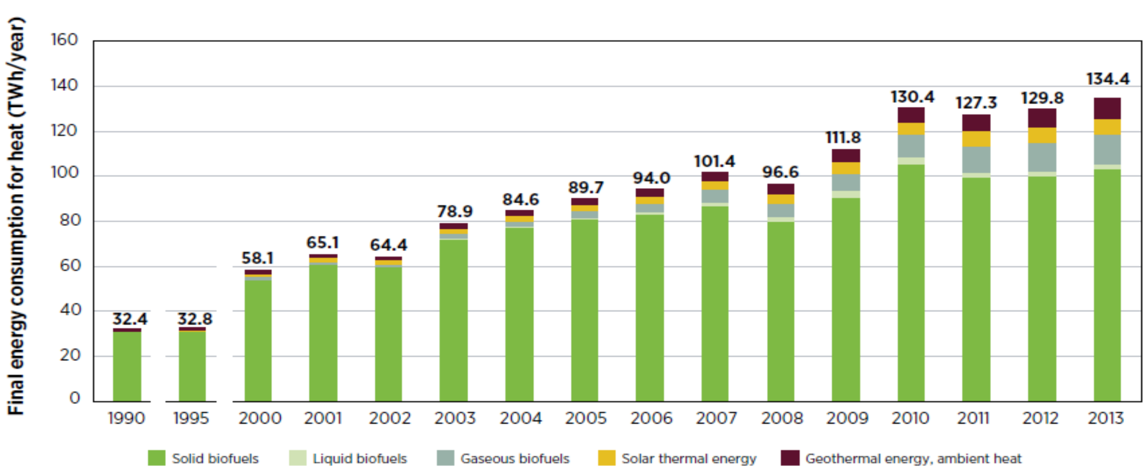


Figure 3: The development of renewables-based heat consumption in Germany

Biomass is the main fuel when it comes to RES consumption (Irena, 2015). However, in recent years more of solar thermal and HP are installed. The district heating (DH) is not so widespread in Germany compared to other Nordic countries, such as Denmark for example. Due to the widespread areas (low heat density) and the fact that in the past the heat was based on coal and individual boilers, the DH share in Germany stands only at 10% (Litz, P.)

1.3 Transport sector

Germany has one of the biggest car ownership rates in the world. However, when it comes to RES, this sector is the most problematic. It has the lowest RES share, standing around 6%. Biofuels takes the biggest share in this percent (Figure 4).

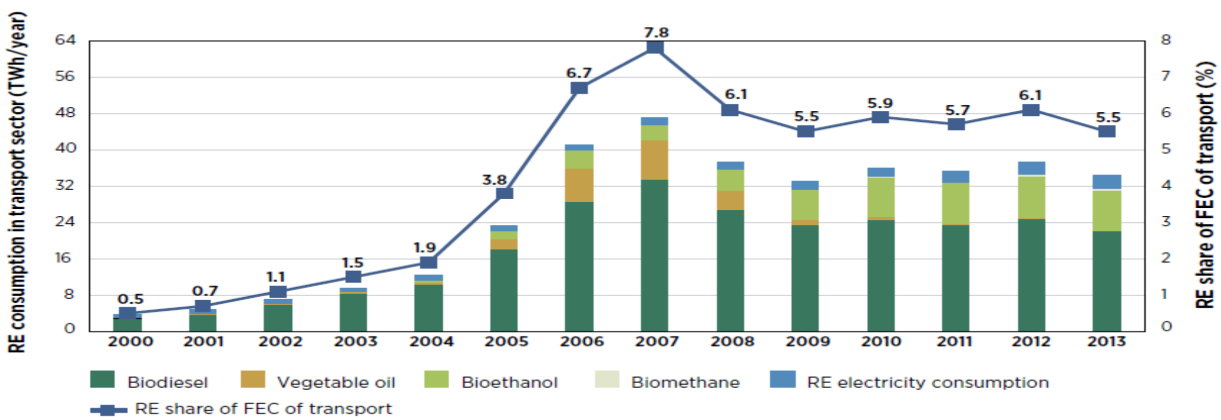


Figure 4: Renewable energy use in Germany's transport sector, 2000-2013

However the number of cars which uses biofulels stopped growing, where electric cars (EVs) numbers currently grow the fastest, but not enough to reach 1 million targets by 2020 (Irena, 2015).

1.4 Current electricity storage situation in Germany

Besides the focus on cross-section electricity integration, these projects also will focus on different electricity storage technologies. At this moment, like in most countries around the world, pumped hydro power is the most widespread electricity energy storage mode (Figure 5).

	Electro-mechanical	Electro-chemical	Thermal Storage	Pumped hydro storage	Grand Total
China		0.1	0.1	32.0	32.1
Japan		0.3		28.3	28.5
United States	0.2	0.7	0.8	22.6	24.2
Spain	0.0	0.0	1.1	8.0	9.1
Germany	0.9	0.1	0.0	6.5	7.6
Italy		0.1	0.0	7.1	7.1
India		0.0	0.2	6.8	7.0
Switzerland	0.0	0.0		6.4	6.4
France	0.0	0.0	0.0	5.8	5.8
Republic ofKorea		0.4		4.7	5.1
Grand Total	1.1	1.6	2.3	128.1	133.1

Figure 5: Stationary energy storage power capacity by technology type and country, GW

It can be seen than other storage modes, like thermal storage and batteries numbers are almost insignificant (Irena, 2017). However, this numbers should change in the upcoming decades. There are many discussions what kind and how much of electricity storage technologies are needed in Germany, where intermittent RES will play the biggest role in the future.

The increasing hours of excess electricity production (EEP) from RES will demand more flexibility in the system, thus automatically the need for energy storage will grow. This future situation will be the center of this study and will be elaborated more in the following chapters.

1.5 Problem formulation

1.5.1 Excess electricity production

It is expected that by 2030 RES share in the electricity sector in Germany will reach 65%, and in total energy consumption will go up to around 30% (Irena, 2015). One of the reasons of this rapid RES capacity expansion is falling cost of technologies (Figure 6, Agora Energiewende, 2018).

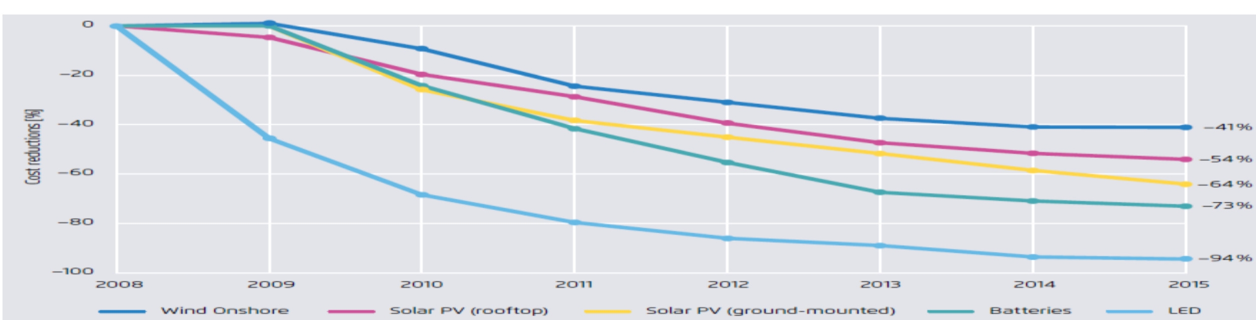


Figure 6: The falling costs of key energy transition technologies since 2008

In addition to this, after changing the feed-in-tariff system to the auction system in Germany, where the lowest bid wins the auction, prices were pushed even further down. In the latest auctions the price for the solar PV projects fell below 5 ct euro's per kWh (cleanenergywire). Basically it means that wind power and solar PV now could be considered competitive with conventional power generators.

The increasing penetration of RES, primarily wind and solar PV, will create the situation in the electricity sector where at times of high wind and solar resources, there will be hours of excess electricity production. And to deal with this amount of surplus generation, different solutions will be needed. One study had simulated the wind power load curve for 2030, and then compared to 2008 load curve (Figure 7). Also in the same figure it was try to show that the pumped hydro capacity will not be adequate. It will cover partly one day's excess production of wind power (IEC, n/a).

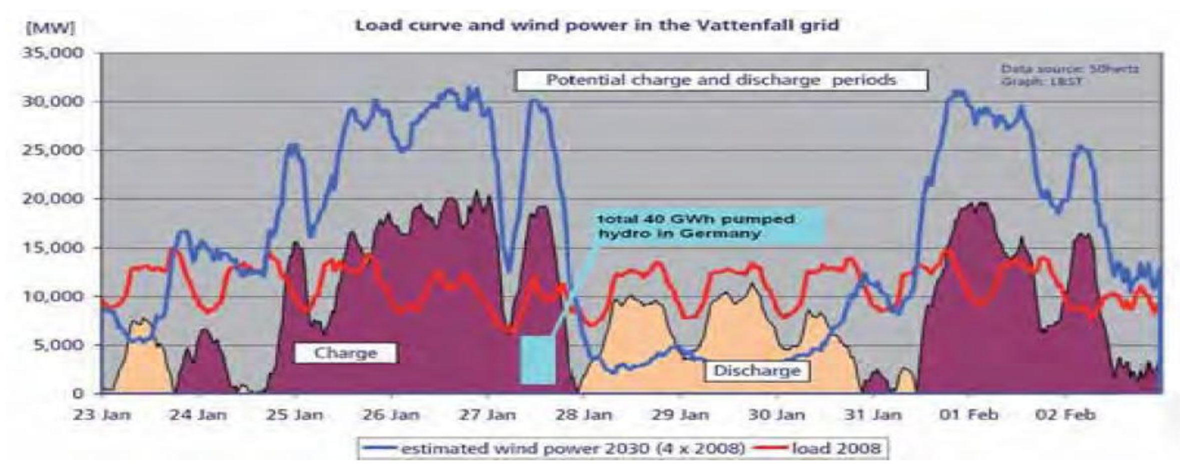


Figure 7: Load curve (red) and wind power (blue) in the Vattenfall grid (north-east Germany):charge and discharge volume in 2030 in comparison with pumped hydro storage capacity

This study also concluded that for balancing the system at least 8,4 TWh of storage capacity will be needed by 2030. Therefore, it can be assumed that there is room for more storage technologies in the upcoming decades.

1.5.2 CO2 emissions

When the weather conditions are unfavorable for RE technologies, then the electricity demand will be covered mostly by conventional power plants which in most cases are based on fossil fuel. This backup capacity production emits harmful CO2 gases to the atmosphere. Coal alone accounts for 42% of all CO2 emissions in Germany, followed by petroleum and natural gas, which emits 33% and 20% respectively (Agora Energiewende, 2018).

For the last decade, even though many carbon-friendly measures were implemented, CO2 emissions level in Germany remained almost stable (Figure 8, Agora Energiewende, 2018). In order to meet climate goals for 2020 and 2030, the transformation to more carbon-neutral energy system will be needed.

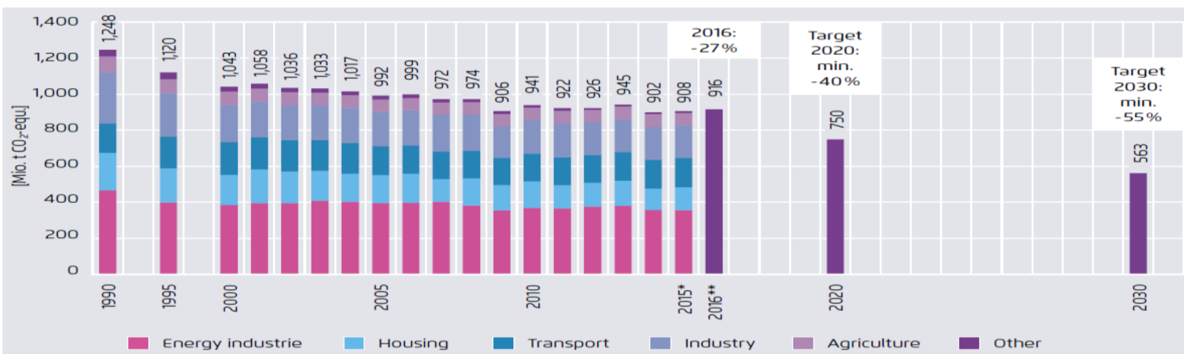


Figure 8: Greenhouse gas emission by sector, 1990 - 2016, together with reduction targets for 2020 and 2030

One of the reasons for this situation is the inefficient control of CO2 emissions in the transport and heating sectors. Indeed, the transport segment is the only sector where CO emissions are rising compared to 1990 level, while the heating sector is considered to be Achilles' heel of the Energiewende until 2030 (Irena, 2015). Furthermore, if there will not be given more focus for these two sectors, all these plans to implement the outlined goals can become the lost legislation (Litz, P.).

Moreover, coal power plants, which due to the cheap fuel and favorable carbon tax system are competitive with less polluted power units are responsible for around 40% of CO2 emissions in energy sector, thus focus only on one sector, as it was done in the past, will not solve the emissions problem (Agora Energiewende, 2017). This could be one of the arguments to focus more on cross-section integration, where for example in the heat sector heat pumps (HP) and electric vehicles (EVs) in the transport sector would possibly reduce the carbon footprint for these segments.

1.5.3 Costs for the whole energy system

In order to meet energy and climate targets, and to transform energy system from fossil fuel based to the system which will rely on RES in the future, considerable amount of investment will be required. First, new capacities of RES will have to be installed, which will require to install new cable lines on a local level (for high share of solar PV), in a country itself (lines from North to South to balance wind and solar PV production) and lastly on a cross-border level (to export EEP and import electricity when the production from RES will fall). Furthermore, even though the share of RES will grow, still the back-up capacity will be required, and with the minimized of hours of production additional support to keep these energy units financially alive will be needed. In addition, the new technologies expansion of EVs park for example, will demand more charging stations and new infrastructure in roads. All these changes will be hungry for new investments.

In general, this project will try to give answers for a few problems, how to reduce the costs, CO2 emissions and the amount EEP for the whole energy system.

1.6 Research question

This study will try to find a cost-effective ways how to integrate EEP mainly from wind power and solar PV. The possibility will be examined to utilize this surplus electricity domestically to other sectors instead of exporting electricity at lower price through the interconnectors to neighboring countries. Electricity storage technologies will connect the link between electricity and other sectors, such as heat and transport, which are responsible for a significant amount of total CO2 emissions.

In addition, integrated electricity should decrease the working hours of conventional power plants fed on fossil fuels, and thus the CO2 emission level possibly should decline as well. Overall, cross-sector integration approach should reduce the fuel consumption and the cost for the whole system (Mathiesen, Lund, 2015).

After indentifying energy problems and considering possible ways to solve these problems the research question can be formulated:

To what extent cross-sector excess electricity integration into heating and transport sectors could reduce the CO2 emissions and the costs for the whole energy system in Germany by 2030?

The research question is illustrated by graph (Figure 9), where challenges, solutions and possible results are indicated.

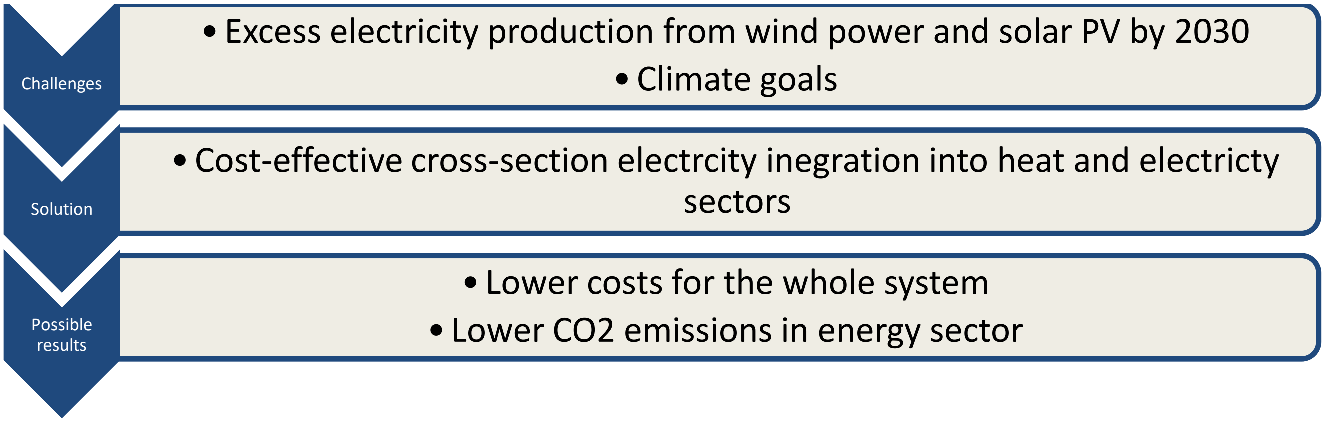


Figure 9: The research question illustrated by the graph

1.7 Delimitations

The research question is formulated in a broad range, and due to the complexity some solutions to the problem which also can be part of the answer will be neglected in this study. This delimitations chapter will try to give arguments why some aspects considering the context of this report are relevant to include and why some are not.

To start with, it needs to be said that the timeframe for this study is set to be until 2030. It can be considered that the energy transition at least in Germany can be divided into three parts. The first one lasted from 2000 to 2015, and the most emphasis was placed on power sector, where generous feed-in-tariff scheme helped to increase RES in electricity sector to 30%.

The second part, which timeframe is from 2015 to 2030, the focus is on climate goals, how to lower the transition costs, and more attention is given to heat and transport sectors. Furthermore, during this time the nuclear power will be phased out and coal power plant production should be reduced. Their role will be taken by wind power and solar PV which share in the electricity sector should grow to 65% (Agora Energiewende, 2018).

The third part which will last until 2050 will include even more RES, up to 80% of total energy consumption. At this time period in order to accommodate intermittent RES, differently than is the second state, storage technologies will be necessary. And new, advanced technologies which at this moment are too expensive, supposed to be available at that time for the market.

Therefore, the chosen timeframe for the study (2015-2030) basically cut the possibility to simulate more advances technologies in EnergyPlan, such as power to gas or hydrogen for transport as an example.

Most of the sources claim that advanced electricity storage technologies are still too expensive to be installed on the market, and cheaper, tested options already exist (Agora Energiewende 2014; Irena 2015; Mathiesen, Lund, 2015). The second argument why there is no need for additional storage technologies is that the RES by 2030 will not exceed 70% share in the electricity sector, thus the demand for so called advanced technologies will grow faster only after this period, where much more flexibility will be needed. Also at that time they will be more developed and more competitive.

Even some technologies are not suitable for this project context, still some considerations about them will be given. To start with hydrogen, one study claims that if excess electricity will be used to produce hydrogen which will be injected into natural gas grids (10%), and then would be used for gas power plants, this approach would let to have approximately 8,2 TWh of flexibility in the system by 2030. This amount can be equaled to one month's needed electricity storage demand by 2030 (IEC, n/a). Another application of hydrogen in the future can be found in the transport sector. Hydrogen can be produced much cheaper, 1-2 EUR cent/kWh in countries located close to the equator where there are plenty of available sun resources. Thus, inexpensive hydrogen could be imported into Germany and could outcompete other transport inputs such as electricity, diesel or petrol (Lewe, H-U).

Next, electricity storage technology which will be not included in this project is batteries. And for this storage mode it's hard to find arguments why it cannot be part of the energy models. Currently the price to store electricity in batteries is too expensive compared with other alternatives (Lund, Østergaard, 2016; Irena, 2015). However by 2030, especially in combination with solar PV, in terms of the capacity, batteries will rank second after pumped hydro power, and will play a big role to balance electricity spikes (Irena, 2015). Even though they can be competitive to HP or EV at that time (2030), the project will focus on cross-section integration. Therefore, batteries will be placed over project's boundaries.

Nevertheless, in some models the expansion of EVs capacity will be analyzed, which contains batteries as well. So the impact for the system can be assumed will be similar if the small scale batteries capacity would be increased.

One technology which is fully developed, competitive and can be carbon-neural is DH and CHP units. The reason why this technology will not be discussed further in this study is because due to historical reasons heating in Germany was based on individual heating. And now to install new pipe systems under already established cities could be not economically viable solution on a big scale (Litz, P). Nevertheless, DH projects are implemented mostly in North of the Germany where there are plenty of wind power production and cities are more dense.

Moving to the next boundary, it needs to be noted that Germany is well connected to neighboring countries, thus the security of supply is rather high (Litz, P). Even though Germany has many benefits of importing and exporting electricity through interconnectors, this project, as it was already few times mentioned, will focus only on cross-section integration. And in particular the emphasis will be given to electrification. Therefore, even technologies ready for the market such as biofuels in the transport sector or solar thermal in heating sector will not be discussed.

Finally, this study will focus only on technologies which by 2030 suppose to be competitive to produce energy without support from the outside. Thus, there will not be policies discussed which could bring new technologies to the market.

1.8 Projects structure

In total the project will consist of nine chapters (Figure 10):

Chapter 1: Introduction will present Germans energy system in general, then problems will be identified from which research question will be formulated. Finally, it will be ended with the delimitations sub-chapter where projects boundaries will be outlined. **Chapter 2: Methodology** will consist of two parts, EnergyPlan software program and interviews. EnergyPlan working principles will be explain in details, and the reasons will be given why particular simulation strategy is more suitable for this study. **Chapter 3: Theory chapter about the electricity integration** will try to stand on other studies shoulders to prove that considering studies problem formulation some technologies are more relevant to use, while other are not competitive yet. **Chapter 4: Technologies** will give a brief description of HP and EVs. **Chapter 5: The data for the scenarios** will give arguments of particular choices of the information used to build the models. In addition, the reference scenario will be verified in comparison to other studies results. **Chapter 6: Technical-economical analysis and results** will compare all models outputs and will argue why they are different from each other. **Chapter 7: Sensitivity Analysis** will test two possibilities of increasing the HP and V2G cars capacity and reducing prices of the same technologies. **Chapter 8: Discussion** will discuss the validity of the results and give some insights for possible future studies. **Chapter 10: Conclusion** will answer the research question and conclude all studies work.

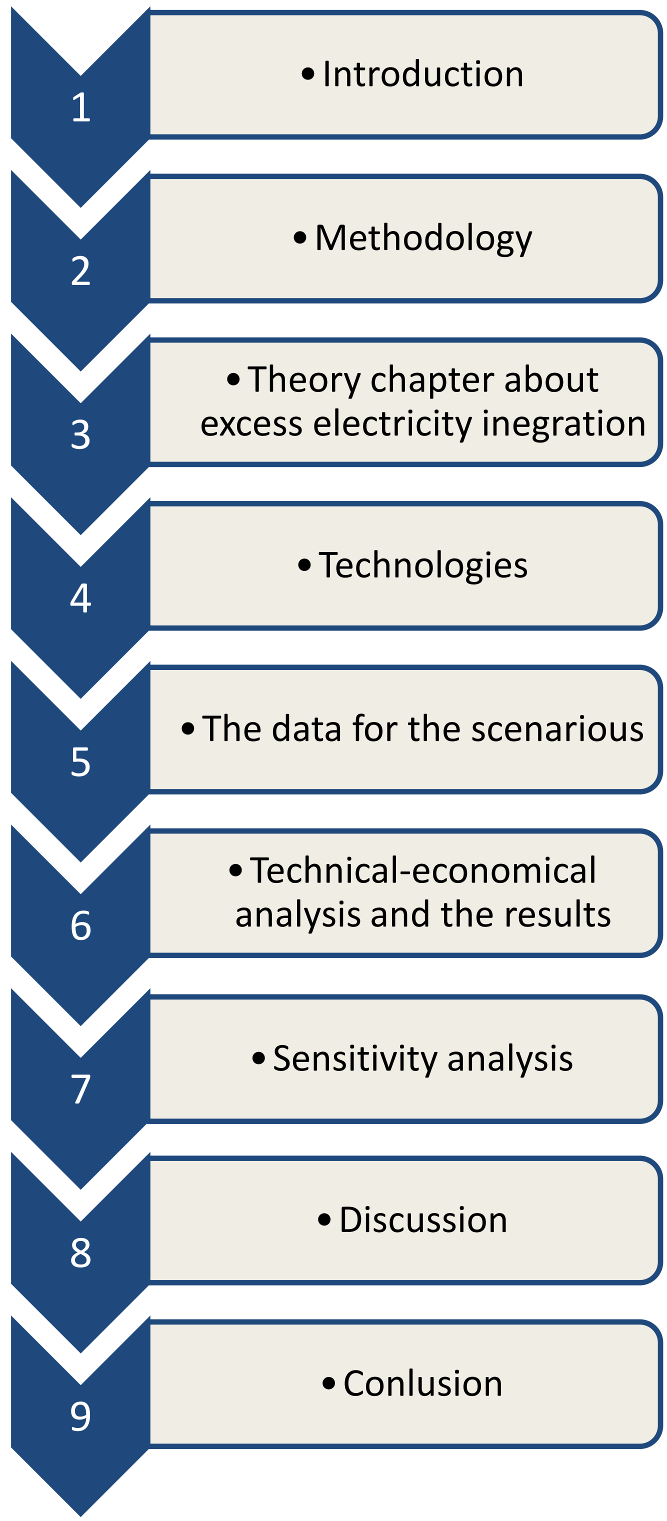


Figure 10: Project's structure

2.0 Methodology

This chapter will be comprised of two methodologies: interviews and modeling program. The software, EnergyPlan, will be described and reasons will be given to justify programs applicability for this study needs. Then interviewed people view on the future energy systems in Germany will be presented.

2.1 EnergyPlan

This energy modeling program was developed at Aalborg University and continuously updated since 1999. This program is designed to model different energy systems on a countries/national level. Though local energy systems had been simulated as well (Lund, 2017).

Analysis in the program is carried out on hourly basis for a period of one year. The simulations are based on input/output data. The inputs can be energy demands, costs, capacities, different energy strategies, while the outputs are energy balances, annual fuel consumption, CO2 emissions, total system costs etc. Figure 11 illustrates the relationships in EnergyPlan between inputs, outputs and regulation strategies (Connolly, Lund, 2010).

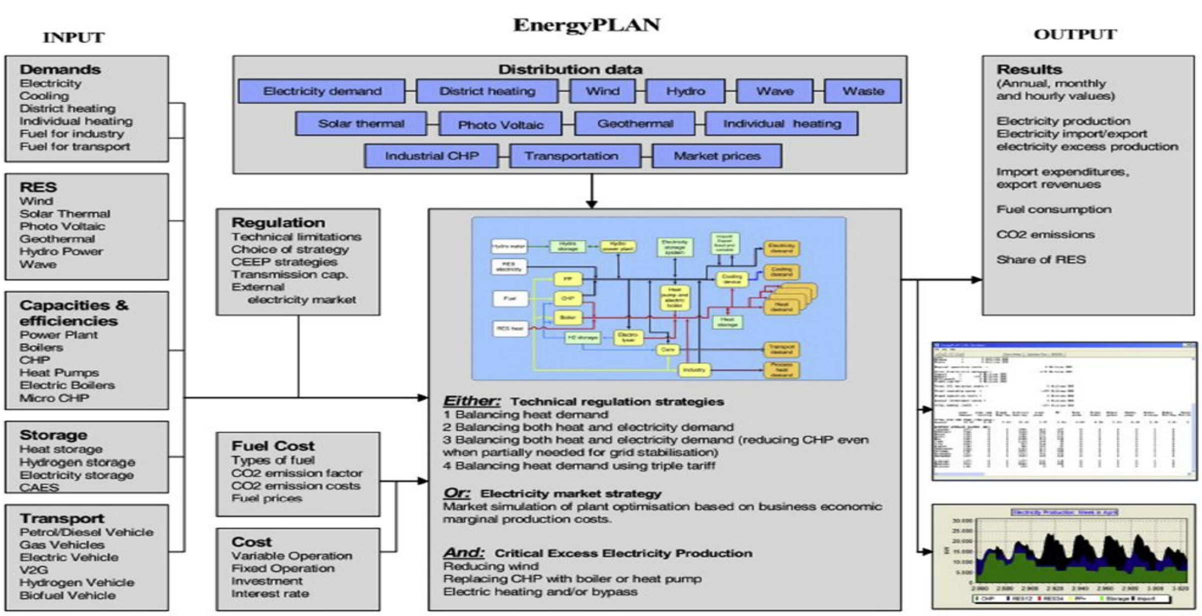


Figure 11: The relationship between the input and output data in EnergyPlan

There are two main strategies in EnergyPlan to carry out energy analysis: Technical simulation and Market-economic simulation.

2.1.1 Technical Simulation

For the technical simulation inputs such as energy demands, efficiencies, capacities are necessary, while the generated outputs are annual energy balances, fuel consumption and CO_2 emissions. Basically in this strategy the demand has to be met by the supply.

If it not the case, than electricity is imported from the external energy market, and if there is a surplus electricity production then the energy is exported. However, this simulation seeks to reduce the amount of imported electricity (Lund, 2017)

2.1.2 Market-economic simulation

The market simulation focuses more on supply side than demand. Meaning than the priority is set to optimize the production in order to generate the highest profitability for energy units. While the impact for the whole system, such as the lowest fuel cost for example is not considered. For the profitability calculations, differently than in technical simulation variable costs are needed. This simulation when the production is based on marginal production cost resembles NordPool electricity market. Furthermore, in the market simulation electricity exchange markets are included. Therefore, the calculations are made if it is more beneficial in terms of profitability for the energy system to import electricity from abroad or to produce energy domestically (Lund, 2017)

2.1.3 The strategy for the project

In order to set the right simulation strategy for the project, first the desired results should be outlined. In this project case, the research question is formulated in a way that the outputs of the modeled scenarios should identify the lowest fuel-consumption (automatically CO_2 emissions as well) and the lowest costs for the whole energy system. Technical simulation is designed to reduce the fuel cost for the whole system, where market simulation optimizes focus on specific energy plant to produce energy at the lowest price possible (Connolly, 2015). And finally technical simulations can model future energy systems, which will be based on high share of intermittent RES, more accurate than market simulation because by including capital costs, not only variable costs can identify the least cost solution for the whole system.

After considering different arguments, technical simulation was opted over market-economic simulation. And now technical simulation will be explain in detail.

Technical simulation has four options to choose from (Figure 12):

- Balancing heat
- Balancing heat and electricity
- Balancing heat and electricity (plus grid stabilization)
- Balancing heat demands using triple tariff

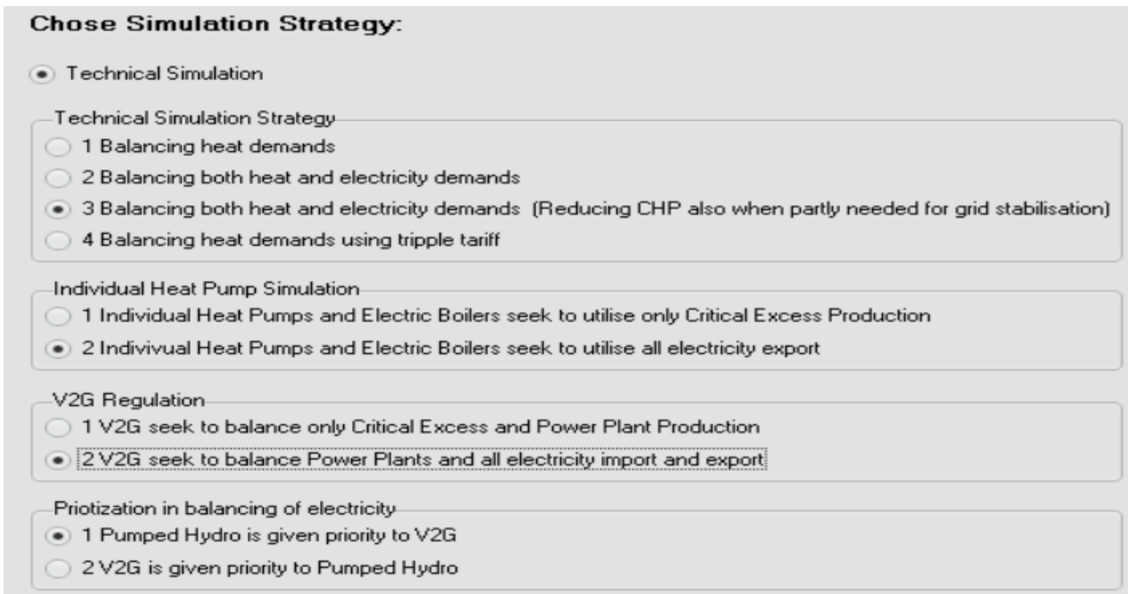


Figure 12: Simulation strategy for EnergyPlan

For this project technical simulation strategy number 3, Balancing both heat and electricity demands (Reducing CHP also when needed for grid stabilization) had been chosen. Basically it means at times when there is an excess electricity production in the system CHP production is reduced. Also the production is reduced when there is a need for grid stabilization (Connolly, 2015)

However, technical simulation is just one part of this study. The second part is to calculate socio-economic costs, which include fuel costs, variable operational costs, investment costs, fixed operational costs and CO2 costs. The main reason for this calculation is to find out the least cost solution for the whole system which is related to technical simulation (Lund, 2017). The difference between socio-economic simulation and market simulation is that the first one excludes taxes why the market simulation includes.

There are even more simulation options to choose from (Figure 12). It was chosen that HP and V2G will utilize all electricity export, not only critical excess electricity production.

2.1.4 Literature review of similar studies done with EnergyPlan

Only the literature which is related to the EnergyPlan software and the technologies described in this study will be introduced. The reviewed literature should contribute to the methodologies, specifically to prove that EnergyPlan program is a suitable choice for this project.

Few studies by employing EnergyPlan had tested the feasibility to integrate variable electricity production from RES sources. One study made a comparison between cross-sector and cross border integration. For cross-border integration technologies such as HP, CHP with thermal storage and EVs had been used to prove that that this way to deal with excess electricity production from RES can reduce fuel consumption considering the whole energy system (Thellufsen, Lund, 2017). The next study had investigated the possibility to transform Croatia's energy system based on 100% RES production. To accomplish that various energy storage technologies had been considered, such as hydro storage, thermal storage, heat pumps and EVs. It was found that with these measures is it possible to reduce CO_2 emissions for the whole country (Krajacic, Duic, 2011). The other study also concluded that by integrating excess electricity from large-scale wind power to energy storage technologies is it possible to reduce CO_2 emissions (Lund, 2005)

2.2 Interviews

In total two interviews were taken from energy experts in Germany. The first person to interview was Philip Litz, advisor of independent and non-profit organization named Agora Energiewende. It is a think tank and policy institute, which different publications were widely used in this study.

The second person who shared the knowledge about future energy system was Heinz-Uwe Lewe, Policy Officer. He is working at the Ministry of economic affairs, Innovation, Digitalization and Energy division of the state of North Rhine Westphalia.

The information gathered during interviews will be used in this work. Full interviews, with all the questions and answers can be found in Appendix.

3.0 Theoretical chapter about the excess electricity integration

This chapter will start with the basic introduction of electricity storage technologies. Then the description of Smart Energy System will be given to prove that the choice of technologies for the timeframe of this study is relevant. Next, other studies related to Germany's energy future energy systems, and storage in particular, will be analyzed for the same reason as it was did for Smart Energy Systems, try to show that chosen approach how to deal with surplus of electricity is based on already tested methods.

In order cost-effectively utilize large amounts of surplus electricity generation in the future some kind of storage modes will be needed. Therefore, first the introduction of energy storage in general to start with will be given.

Energy can be considered primarily stored or secondary stored (Agora Energiewende, 2014). The first one, which accounts around 80% of all power generation, is fossil fuels. They are stored in chemical energy, and are charged only once, through photosynthesis when in the past were converted naturally into hydrocarbons. Then discharged again only once when are burned in energy units. While the secondary stored group can be charged, stored and discharged many times. These technologies can store electricity in many forms. It can be done electrochemically (batteries), mechanically (pumped hydro), chemically (hydrogen), electrically (superconducting magnets) or thermally (electric boilers, hot water tanks). The application rate depends on many factors such as the cost, geographical conditions, availability of resources etc (IEC, n/a).

In the past energy system was consisted of three main segments: production, distribution and consumption. Now, at the era of rapidly growing share of intermittent energy sources, the demand for storage technologies due to the increasing need for the flexibility is growing. Thus, in the upcoming years storage technologies can be considered the forth pillar of energy systems (Agora Energiewende, 2014):

- Generation: power plant flexibility, cogeneration plants, renewable energy plants (including curtailment)
- Network: network expansion, network conversion
- Consumption: demand side management in the electricity sector and across sectors
- Storage technologies: sectoral energy storage, cross-sectoral energy storage

It can be seen that in the last section storage technologies, the energy storage is separated into two parts: sectoral and cross-sectoral. As it was mentioned in previous chapters, this study will exclude considerations of storing electricity directly to the batteries for example, or will not take into consideration pumped hydro power which probably due to the landscape restrictions, public acceptance will not be expanded (Litz, P., Lewe, H-U.).

The following paragraph will be based on so called Smart Energy System theory, and one of the definitions could sound like this (Connolly, D., Lund, H., 2013), (Figure 12):

'Smart Energy System is defined as an approach in which smart Electricity, Thermal and Gas Grids are combined and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system'

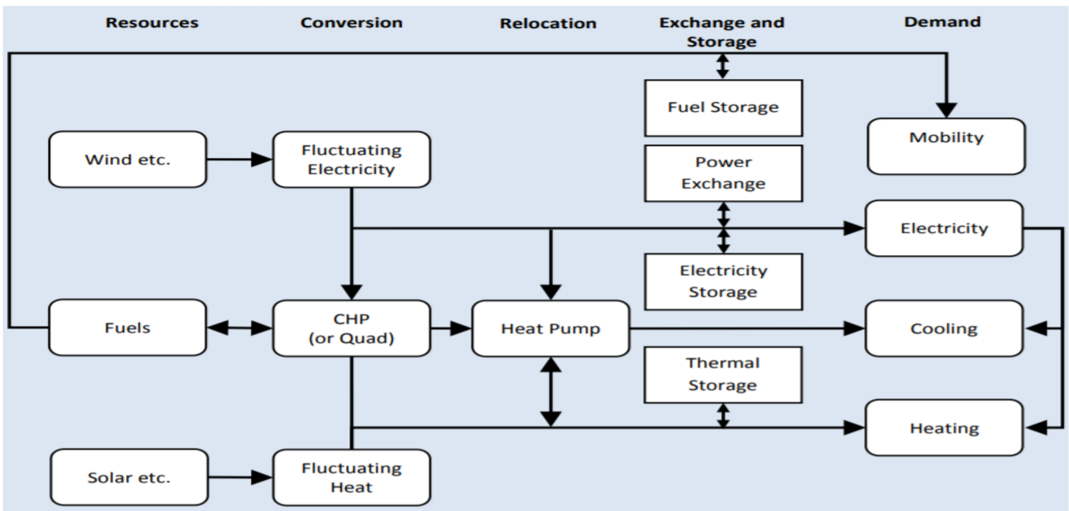


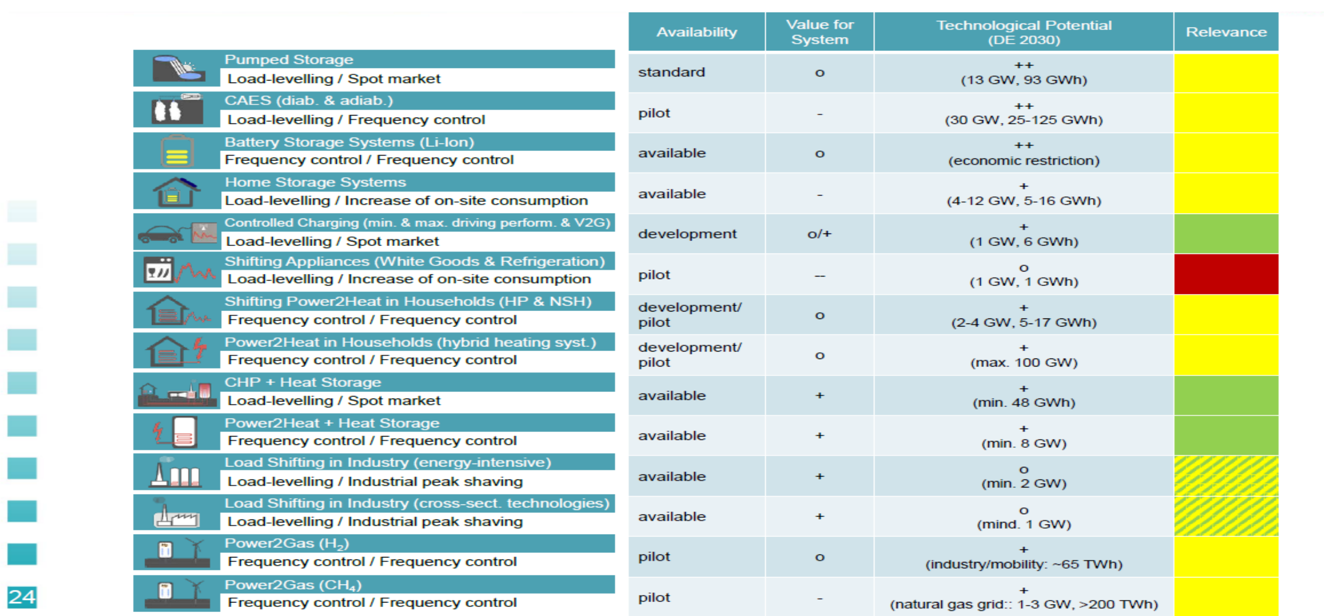
Figure 13: Smart Energy Systems' schematic drawing

According to the Smart Energy Systems theory different RE share for the optimal fuel consumption requires different storage technologies. In one of the studies, different RES shares were tested, and different technologies were used accordingly to prove that by connecting different sectors the fuel consumption and the CO2 emissions for the whole energy system can be reduced (Mathiesen, Lund, 2015). For example when variable RE sources produced electricity doesn't exceed 25% share in the power sector, than the system was capable to integrate this amount without significantly affected electricity grid. However, for fuel-efficient it is recommended to have CHP systems with thermal storage tanks. When the 25% percent is exceeded then it is suggested to connect the electricity and heat sector by installing large scale heat pumps in densely populated areas and individual heat pumps in remote areas in individual houses. Finally, when RE share stands at more than 45% for optimal integration transport sectors needs to be electrified. This integration theory can be broken down into these steps (Thellufsen, Lund, 2017):

1) District heating with CHP plants and thermal storages.
2) Implementation of heat pumps in the district heating system.
3) Electric vehicles
4) Conversion of excess electricity to electro fuels to provide fuel for power plants and transport sector.

The last step, number four, will not be discussed because RE share in Germany by 2030 should not go up more than 65% and more advanced storage technologies such as the production of the synthetic fuels will not be included in this report.

In addition, the assumption that surplus electricity can be stored cost-efficiently in different sectors is also recognized in some studies which had modeled future energy storage technologies in Germany. One project indentified the availability, technological potential and the relevance of storage technologies for 2030 (Figure 13).



	Availability	Value for System	Technological Potential (DE 2030)	Relevance
Pumped Storage Load-levelling / Spot market	standard	o	++ (13 GW, 93 GWh)	
CAES (diab. & adiab.) Load-levelling / Frequency control	pilot	-	++ (30 GW, 25-125 GWh)	
Battery Storage Systems (Li-Ion) Frequency control / Frequency control	available	o	++ (economic restriction)	
Home Storage Systems Load-levelling / Increase of on-site consumption	available	-	+ (4-12 GW, 5-16 GWh)	
Controlled Charging (min. & max. driving perform. & V2G) Load-levelling / Spot market	development	o/+	+ (1 GW, 6 GWh)	
Shifting Appliances (White Goods & Refrigeration) Load-levelling / Increase of on-site consumption	pilot	--	o (1 GW, 1 GWh)	
Shifting Power2Heat in Households (HP & NSH) Frequency control / Frequency control	development/ pilot	o	+ (2-4 GW, 5-17 GWh)	
Power2Heat in Households (hybrid heating syst.) Frequency control / Frequency control	development/ pilot	o	+ (max. 100 GW)	
CHP + Heat Storage Load-levelling / Spot market	available	+	+ (min. 48 GWh)	
Power2Heat + Heat Storage Frequency control / Frequency control	available	+	+ (min. 8 GW)	
Load Shifting in Industry (energy-intensive) Load-levelling / Industrial peak shaving	available	+	o (min. 2 GW)	
Load Shifting in Industry (cross-sect. technologies) Load-levelling / Industrial peak shaving	available	+	o (mind. 1 GW)	
Power2Gas (H_2) Frequency control / Frequency control	pilot	o	+ (industry/mobility: ~65 TWh)	
Power2Gas (CH_4) Frequency control / Frequency control	pilot	-	+ (natural gas grid:: 1-3 GW, >200 TWh)	

Figure 14: The relevance for different storage technologies in Germany by 2030

This study concludes that the most relevant and the biggest potential have three technologies (green light in Figure 13): CHP+heat storage, power to heat+ storage and controlled charging, meaning V2G (IEA, 2016). Moreover, according to the same paper, electricity storage technologies can reduce RES curtailments, especially wind power. Furthermore, installed storage systems can shorten the hours of expensive start-ups of conventional power units.

Finally, it states that the most relevant storage modes by 2030 can lower overall system cots, integrate more RES and reduce the CO2 emissions in the long-term. All of these mentioned parameters will be the main outputs of the scenarios in this study.

Other studies came up for similar conclusions. In order to install and integrate electricity from intermittent RES in a cost-effective way, first heat and electricity sectors needs to be electrified. In heat sector DH systems should be based on CHP units installed together with hot water tanks and large-scale HP, where in individual sector inefficient boilers fed on fossil fuel needs to be changed with small-scale HP, and lastly more V2G cars should be seen on the roads to balance the grid (Irena 2015)

4.0 Technologies

In this chapter three technologies (HP,TS and V2G) simulated in this project will be presented.

4.1 CHP plants and thermal storage

Even though CHP units will not be included in alternative energy models in this project, it is worth to discuss the combination of CHP and TS, as it can significantly contribute for the balancing of energy systems.

The CHP plants participate in two markets, heat and electricity. Depending on the demand, the CHP role in the markets constantly changes. At times of reduced production from intermittent energy sources CHP units assist as a backup capacity and cover both, the heat and electricity demand. If the electricity demand is covered by cheaper production modes, like wind power and solar PV, then the heat demand is covered by thermal storage, which could be filled up during hours when the heat demand was lower than the electricity demand. This process can be better illustrated in Figure 14.

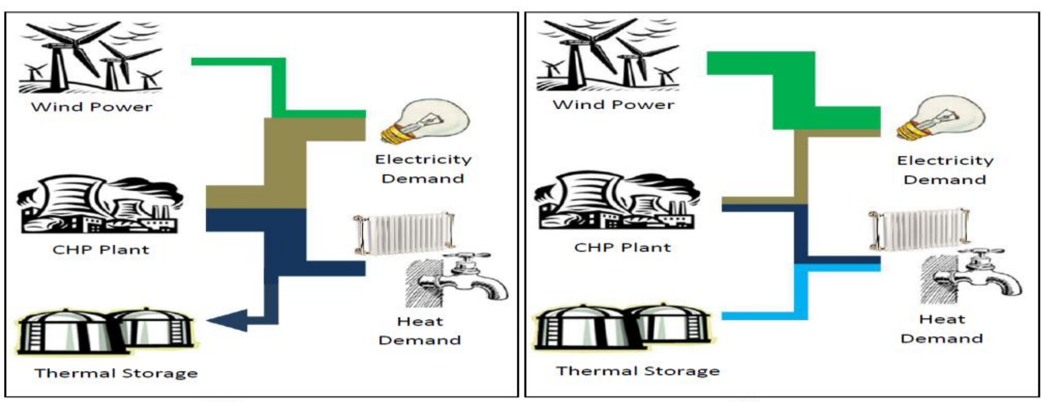


Figure 15: Energy system with district heating and thermal energy storage during (a) a low wind scenario and (b) a high wind scenario

Thermal storage adds the flexibility for CHP units and thus reduces the total fuel consumption. This figure above resembles already discussed technical simulation strategy number 3 (Connoly, 2015). Furthermore, it is of the cheapest way of storing energy. According to the one study, to store energy in thermal storage tanks is approximately 100 times cheaper compared to the electricity storage technologies such as batteries for example (Lund, Østergaard, 2016).

4.2 Heat pumps

There are two main types, compression and absorption HP. The main difference is that compression HP for input uses electricity while absorption HP utilizes some form of heat in a form of steam, flue gas or hot water. Compression HP is more efficient. They coefficient of performance (COP) is around 3-5 while absorption HP is approximately 1,7 (Energinet, 2018).

HP is the technology which in the future can work in synergy together with the increasing number of RES. Installation of heat pumps in energy systems would utilize excess electricity generation from power units such as wind or solar PV. This would reduce the amount of exported electricity to neighboring countries, and reduce the overalls cost for the whole system, and finally will make wind power production more valuable (Mathiesen, Lund, 2015; Mathiesen, Lund, 2009). The reasons for these benefits is that at hours of surplus electricity production, the market prices drop significantly (sometimes to even negative prices), therefore it is cost-effective to transfer cheap electricity into heat energy. This can be illustrated by figure 15, where it is shown that when wind and solar PV production takes over, the day ahead power prices fall down (Bloomberg New Energy Finance).

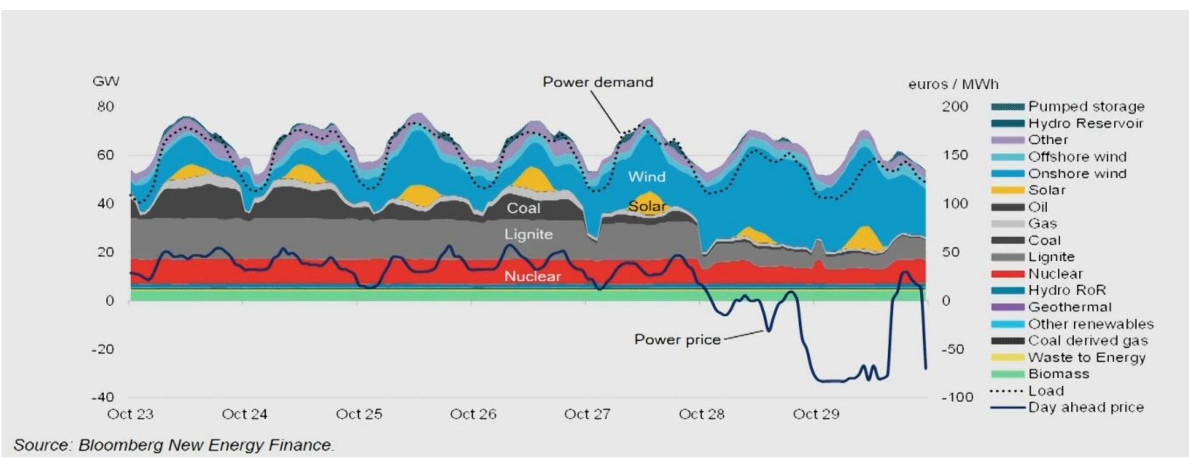


Figure 16: The day ahead prices the energy sources used for power demand in one weeks period in Germany in 2017

4.2.1 Large-scale heat pumps

Large-scale heat pumps can be a part of DH systems. They could provide flexibility for CHP plants and for the whole system which is based on variable RES (Averfalk, Ingvarsson, 2017). Increasing penetration of intermittent RES will increase the amount of hours of surplus electricity production. Large-scale HP could utilize this inexpensive electricity and transform into heat in an efficient way.

Moreover, assuming that large-scale HP would take some operating hours from CHP units, fuel consumption would be reduced, automatically CO2 emissions as well. If renewable energy source such as biomass are burned in CHP plants, it is also beneficial for the society to lower its consumption as it is predicted shortages of this resource in the future (Irena, 2015).

4.2.2 Individual HP

Individual HP similarly as large-scale HP can utilize excess electricity production from wind power or solar PV. There are few types of individual HP such as air to air, air to water and ground-sources. The most efficient is considered to be ground-sauce HP. Also this type of HP can be installed together with a thermal storage which at hours of expensive electricity can cover the heat demand without using any inputs (DAE, 2016).

Individual HP can play a big role in the future energy systems. In rural areas where due to low energy density DH projects cannot be economically feasible, small HP could change individual boilers based on fossil fuel. Furthermore, new stricter regulations in EU will force new house owners to install HP in order to meet energy efficient standards (Lewe, H-U).

4.3 Electric vehicles

There are two types of electric cars. One type use only batteries, while other type, hybrids, can run either on batteries or get the energy from the fuel system similar to the conventional cars. Also cars which are running only on batteries can be divided into two categories like grid to vehicle (G2V) and vehicle to grid (V2G). The main difference is that V2G due to the technological update can do both, charged the battery from the grid and discharge electricity back to the grid, while G2V has only one charging mode.

According to the different research papers EVs can facilitate in the integration of intermittent RES. Already mentioned Smart Energy Systems theory claims that by increasing the number of EVs on the roads would increase the fuel efficiency (Mathiesen, Lund, 2015). Thus, reduced fuel consumption (which is mostly fossil fuel in the transport sector) also cuts CO2 emissions and costs for the whole system. To elaborate more on this statement, the conventional cars are not as efficient as EVs. Conventional cars which running on diesel or petroleum coverts fuel into useful energy with 20-30% efficiency, while EVs energy utilization is 90-95%. When it comes to RES integration it is foreseen that G2V will play a big role in so called demand side management (DSM).

Stored electricity in batteries could be recharged to the grid in order to regulate the frequency, cover the peak loads or in general compensate the electricity production shortage in the system (Irena, 2017).

Another important aspect related to the feeding the grid from G2V is the flexibility. It is assumed that is near future consumers will get signals when is more beneficial financially for them to recharged they car batteries. This flexibility should help to ensure that the electricity demand every hour is met.

When it comes to CO2 emissions, the saving really depends on what kind of fuel was burned to produce electricity which was used to charge the batteries. It is accounted that in order for EVs to have a positive carbon footprint compare to the hybrid cars, the amount of CO2 should not be exceeded by 600 grams per 1 kWh of produced electricity (Irena, 2017).The trend is moving towards the energy systems with increasing share of RES, therefore it can be assumed that the carbon footprint of EVs in the future will only decline.

5.0 The data for the scenarios

In this chapter the data used for the reference and the cross-section scenarios will be presented. Cross-section scenario will contain four models: V2G, HP, HP+Storage and V2G+HP+Storage. The inputs, necessary to build the models will be explained and arguments of particular choices will be given. Figure 16 below illustrates how different models are related to each other, and also show the analysis plan for this study.

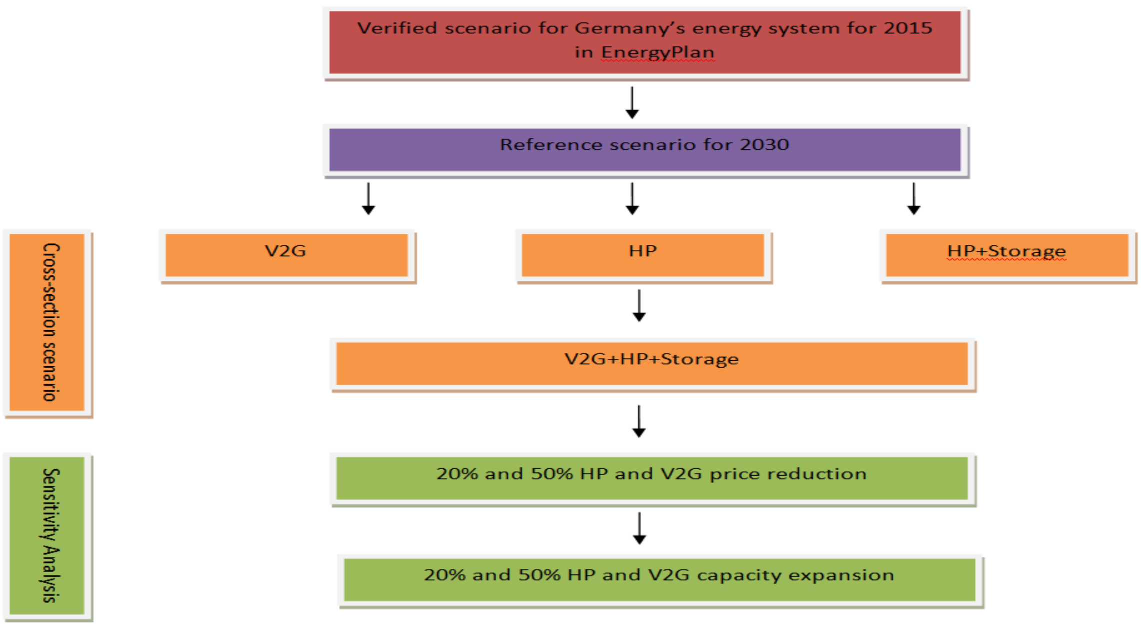


Figure 17: The links among different scenarios and analysis plan of the study

It needs to be noted that this chapter will describe only reference and cross-section scenarios. Sensitivity analysis results will be compared with the previous models in Chapter 7.

5.1 Reference scenario

The first model is the reference scenario. This scenario should resemble most possible energy system in Germany by 2030. One of the purposes of the reference scenario is to have a starting point, the foundation on which other models can be built. Also the reference model will be compared to other four models to find out if they could improve the energy system parameters, such as CO2 and annual costs.

This scenario will be built on already existing model (EnergyPLan file). This file was used for the study, which analyzed the feasibility of thermal solar systems in the future energy systems in four different countries (Mathiesen, Hansen, 2017).

One of the countries was Germany, therefore all the data, including the distribution files, will be used as the starting point for this scenario as well. Off course borrowed file in EnergyPlan will be updated. This study is designed for 2030, while the borrowed model is for 2015.

The data for the reference scenario had been taken mostly from two studies (Agora Energiewende, 2018; Irena, 2015). These studies were made to predict how Germans energy system could like for 2030. Moreover, a strong emphasis was placed on RES, different sectors development and climate targets. Basically, these studies modeled future energy systems which could be able to match energy and climate goals. It means that the reference scenario will not be typical business as usual case. And the argument for this is to build a starting model which would be as close to the reality as possible, even though future predications will always include uncertainties.

However, the data used to build the models was taken from other papers as well. EnergyPlan software requires rather specific information for some sections, which is hard to obtain from only few sources.

5.1.1 Energy demands

Before starting to describe the specific energy demands for every sector, it needs to be noted that due to the expected efficiency measures, such as building retrofitting and general different efficiency policies, it is predicted that primary energy consumption should drop around 30% compared to 2015 level (Agora Energiewende, 2018).

5.1.2 Electricity demand

The total electricity demand for 2030 was set to be 568,5 TWh (excluding import/export), (Irena 2015). In this number electricity needs for transport (2,5 TWh), electricity needs for individual HP (40 TWh) and electric cooling (17,7 TWh) are included. After adding fixed import/export (44 TWh) number, it resulted that the total electricity demand is 612,5 TWh .

One of the reasons why electricity demand for 2030 dropped insignificantly compared to 2015 data, is that the electrification of the heating and transport sectors reduces the efficiency measures in this sector (Agora Energiewende, 2018)

5.1.3 Heating demand

The heating demand in EnergyPlan software is divided into two parts: individual and DH. Starting with the individual heating, first the average demand for households needs to be set. The average heating demand in 2030 supposes to be 25% lower compared to 2015 heat demand (Agora Energiewende, 2017). It resulted that the expected average need for space heating and hot water will be around 11250 kWh/year.

EnergyPlan program, by knowing average household consumption and total heat demand, calculates automatically the number of individual houses (Lund, 2017).

After that, fuel inputs (measured in TWh/year) and the efficiencies of different boiler types such as coal, oil, natural gas and biomass boilers are specified (Figure 17).

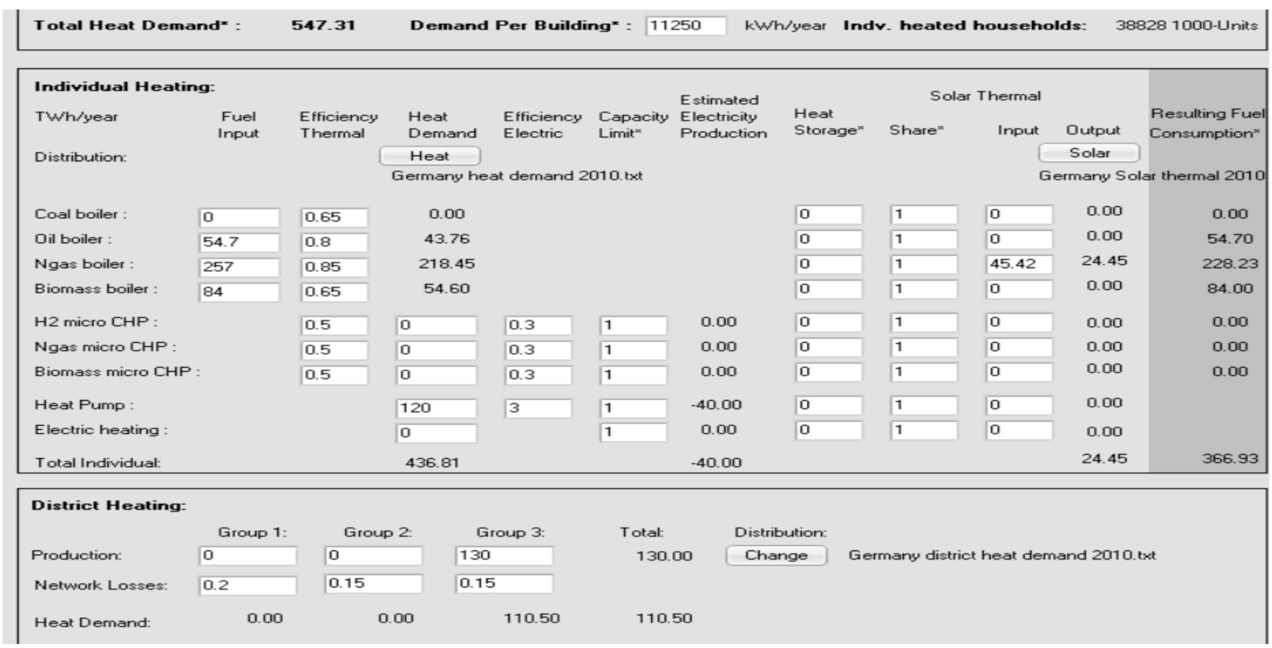


Figure 18: The data for the heat demand

The basic trend from 2015 to 2030 is that the oil fired boilers numbers will be reduced significantly, while the share of gas-fired boilers will remain almost the same. The biggest change will be for HP technology, it is predicted that they share in total heating demand will grow from 1% to 22%, and by 2030 around five millions of HP will be installed (Agora Energiewende, 2017).

There are three different groups for district heating sector. The first one represents the energy system where only heat boilers cover DH demand, the second group indicates decentralized CHP plants and the third centralized CHP plants (Lund, 2017). The DH demand for 2030 was set to be 110 TWh. It results that the total demand for total heat demand is 547 TWh (Agora Energiewende, 2017).

The solar thermal by 2030 should supply around 24,45 TWh of heat (Irena, 2015)

5.1.4 Cooling demand

Only annual cooling demand was specified, which is 17,73 TWh/year (BluePrint Germany, 2009).

5.1.5 Industry demand and fuel

The information about energy consumption for industry by energy source was taken from one of the reports about future Germany's energy system (BluePrint Germany, 2009). It is predicated that by 2030 the industry will be fueled mainly on natural gas.

5.1.6 Transport demand

The energy usage in the transport sector due to the efficiency measures and the reduced numbers of cars which run of fossil should be 30% lower by 2030 compared to 2015 level (Agora Energiwende, 2018). However, still by 2030 most of the cars will be based on petrol and diesel. When it comes to renewable fuels, biofuels and EVs, numbers will stand at 30,0 and 2,5 TWh respectively (BluePrint Germany, 2009; Agora Energiwende; Irena, 2015). In total 1 million EVs will be in the roads, and 60% of them suppose to run only on batteries (IEC, n/a). Its need to be noted, that the number of EVs choice is rather conservative, different sources estimates different predictions, ranging from 1 to 12 millions. Nevertheless, higher EVs figures will be tested in cross-sections models.

5.1.7 Electrical cars

There are two options how EVs can be charged, fixed (Dump charge) or flexible (Smart charge). For this reference scenario fixed mode had been chosen. The technical simulation will consider the electricity demand for EVs as fixed and will base it on distribution file (Lund, 2017).

5.1.8 Supply

5.1.9 Heat and electricity

Currently Germany has the overcapacity in power plants fleet (Agora Energiewende, 2015 (b)). However, in the future when the renewable energy source capacity will be expanded, the need for the back-up capacity will decline significantly, approximately by half (World Wild Fund, 2017). It can be economically difficult for back-up capacity power plants to generate returns on investments with less hours available (Figure 18, Bloomberg New Energy Finance)

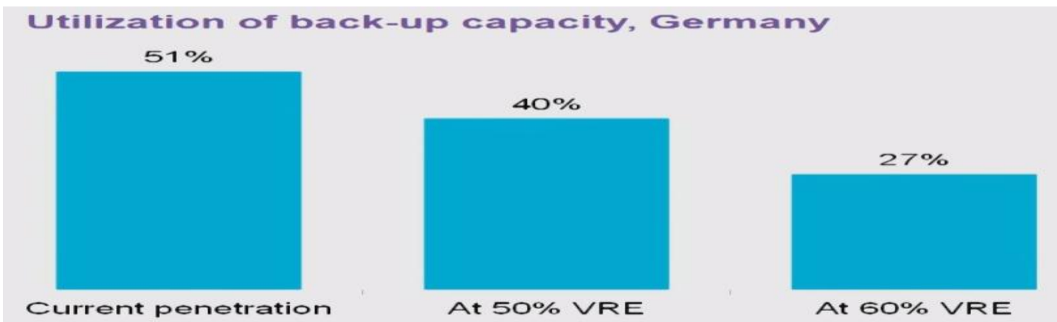


Figure 19: Utilization of back-up capacity in Germany with different variable renewable energy shares

This figure shows that when the variable renewable energy (VRE) sources will reach 60% the need for back-up capacity will drop approximately by half compared to the current RES penetration.

Therefore, for the reference scenario for 2030 the power plant capacity will be halved compared with 2015 models data (Mathiesen, Hansen, 2017). Nevertheless, it will not be the case for central condensing power plants (PP). If the capacity of PP is reduced too much in the system, EnergyPlan starts to show warnings that more capacity in needed or the transmission line capacity is not adequate (Lund, 2017). The optimal number of PP plants for the reference scenario was set to be 52000 MW.

5.1.10 Electricity only

One of the big changes in the electricity sector by 2030 is that the nuclear power will be already phased-out from the system. Nuclear plants production share will be compensated by increased number of wind power turbines (onshore and offshore) and solar PV power plants (91 GW, 20 GW and 86 GW respectively).

It is assumed that the renewable share in the electricity sector will be around 60-65% (Agora Energiewende, 2018).

Furthermore, it is predicted that by 2030 the pumped hydro capacity will be around 5,4 GW and the production from storage will amount approximately 22000 GWh (Irena, 2015).

If it will not be significant delays, the transmission capacity in Germany should be expanded significantly, and reach 31,3 GW (Agora Energiewende, 2015 (b)).

5.1.11 Heat only

This section in EnergyPlan software requires specify mostly renewable heat supply sources, such as solar thermal, HP and excessive heat from industries. The solar thermal share in DH systems was found to be only 0,55 TWh per year (Irena, 2015). Large-scale HP will be introduced into the system in the later models.

5.1.12 Fuel distribution

There are two options how to define the fuel distribution in power plants; the distribution can be fixed or variable. The option fixed indicates how much exactly the specific group of power plants consumed energy, and the option variable shows the ratio among fuels (Lund, 2017). Due to the lack of data of how much every group of energy units will use fuel in the future, it was chosen to use variable option. The most used fuel for heat and electricity production units for 2030 will be natural gas followed by coal and biomass, the ratio goes accordingly 114:66:27 (World Wild Fund, 2017). One of the reasons why biomass will not be the dominate source at the market in the future, because it interferes with food production and the production for renewable fuel (Irena, 2015).

5.1.13 CO2

It was specified how much every fuel after being burned emits CO2 gases (BluePrint Germany, 2009). Off course, coal is the most unclean fuel to burn (emits 103 kg/GJ), while in comparison natural gas emits roughly two times less as coal.

5.1.14 Balancing and storage

In total there are three storage groups: electricity, heat, and liquid and gas fuel.

5.1.15 Electricity storage

5.1.16 Critical excess electricity production

In case there is CEEP in the system (a surplus electricity production when there are bottlenecks in the transmission lines) there are different options in EnergyPlan to choose from of how to deal with this problem (Figure 19). In order to avoid critical excess electricity production, the system can shut down renewable energy plants, replace CHP energy units with boilers, use HP instead of boilers etc. (Lund, 2017).

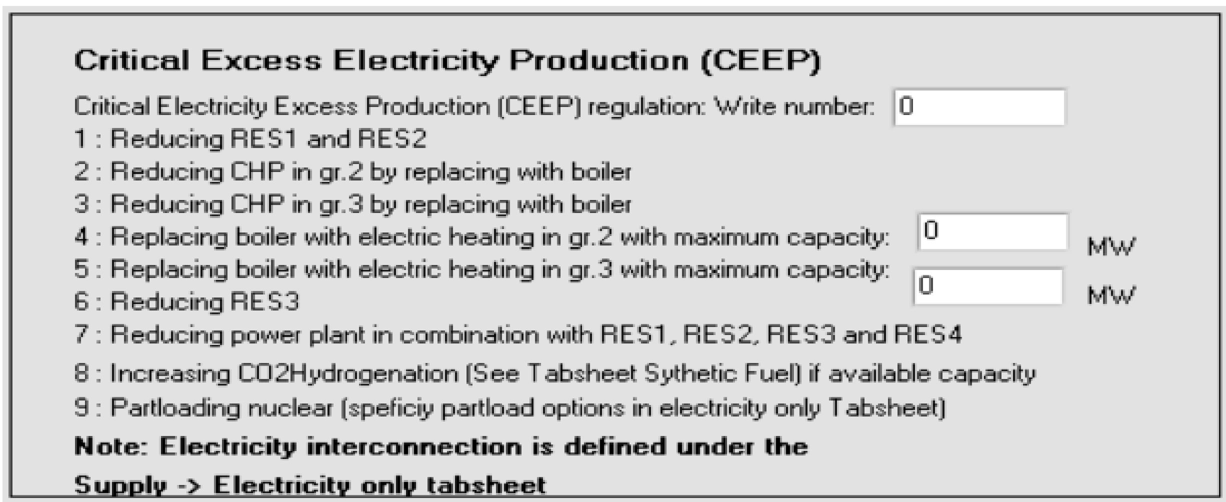


Figure 20: Options to deal with the critical excess electricity production

However, for this study different approach was chosen. CEEP will not be regulated, and the reason for this it to check if cross-section models are able to reduce the possible bottlenecks in the future energy systems.

5.1.17 Electricity grid stabilization requirements

There are few options to choose from how to stabilize the grid. However, due to the complexity only one option, minimum grid stabilization share was set to be 30%. It is recommended share for power units (CHP, hydro power, geothermal) to ensure that the grid is balanced (Lund, 2017).

5.1.18 Electricity storage capacity

In the future it is expected that electricity storage capacity in Germany will be around 8,4 GW (Irena, 2015; IEC, n/a). The biggest share of this number will be taken by pumped hydro power and the rest will go for batteries.

There is also an option to allow simultaneous operation between turbine and pump. It was chosen to allow simultaneous operation, because not only old pumped hydro plants are in this category, which in the past was designed to operate in a way that at night when electricity is cheap to pump water upwards and then release water through the turbine during the day when the electricity price is higher, but also batteries which can be charged and discharged at the same moment.

5.1.19 Thermal storage

Thermal storage in the reference scenario was set to be zero, as the current and future capacity for 2030 is predicted to be insignificant.

5.1.20 Costs

All the costs for this project such as investments, operation and maintenance, fuels, and lifetimes for the 2030 period is incorporated from cost database made by Aalborg University researchers (EnergyPlan, cost database).

5.1.21 Verifying reference scenario models data

Reference scenario was built on already existing energy model, which was already verified in the study about future thermal energy systems in four different countries, including Germany (Mathiesen, Hansen, 2017). The outputs of the model in this study were similar to the real Germany's energy system data for 2015. Therefore, it can be assumed that the starting model is closely resembles real life energy system.

Before starting to verify the reference scenario for 2030, first the accuracy of the data needs to be checked. And to do that, one paper outlines which parameters in particular to follow (Connolly, 2015). These parameters are: energy demands, consumption, energy production for the specific plants, efficiencies and fuel consumption. The input/output final document can be found in Appendix.

In order to verify the reference scenario for 2030, the models outputs will be compared to the two studies data, which were mainly used to build this scenario (Agora Energiewende, 2018; Irena, 2015). Table 1 compares the final outputs of the three studies.

	CO2 emissions, mln, t	Primary enregy consumption, TWh/year	RES share, percent of primary energy, %	RES share, percent in electrcity sector,%	Renewable electricity production, TWh, year
Energiewende, Big Picture 2030	424	2600	31	60	370
Renewable Energy Prospects: Germany	439	2041	37,1	65	376
Reference scenario	460	2342	23,9	63	324

Table 1: Reference model's verification

The main parameters in the table more or less comply with previous studies data. However, one output which is not close is RES share of primary energy. Even though the RES capacities are mostly identical, in this study reference scenario it was assumed that by 2030 most power plants still will run on mainly natural gas and coal. And at times when weather conditions are not favorable for intermitted RES production, fossil fuel consumption will take the biggest share. Another assumption is that other studies for future models for electricity storage considered higher capacities of battery storage, while this study considered rather conservative numbers, and focused more on cross-sector integration.

Overall, it needs to be noted that there is no one right model for 2030. Future projections always will be uncertain. However reliable data gathering can bring energy models closer to the real situation in future energy systems.

5.2 Cross-section integration scenario

The aim of the alternative scenarios is to find out if the integration of surplus electricity production into the heating and transport sectors can reduce the cost and CO2 emissions for the whole Germany's energy system by 2030. To do that, these new models will have to be compared to the previously discussed reference scenario. It needs to be noted that not only two previously mentioned parameters will be compared, but other criteria such as CEEP, EEP, total fuel consumption, PP and CHP electricity production and PP capacity. By considering these criteria, the analysis will be given based on how the energy system (reference scenario) responds to the made changes.

The cross-section scenario basically will be the same as the reference scenario, except that different changes will be made in heating and transport sectors. In first model, more V2G cars will be added to the transport section. Next, individual and large-scale HP capacities in heating section will be expanded. In the third model heat storage will be included to balance HP and CHP units. And finally all of these changes will be included in one model to have a full picture of how and why the cross-section scenario is different from the reference scenario.

5.2.1 V2G

To start with the transport sector, additionally 11 million of V2G cars will be added to the system. It is 30 TWh/year of added electricity demand for energy system (Agora Enegiewende, 2018). The same demand will be removed from petrol section assuming that the e number of cars on the roads by 2030 will be same (44000). Even though it's rather ambitious number to reach, still majority of cars by 2030 will be run on fossil fuel, such as diesel or petrol.

EnergyPlan, in order to calculate how much V2G cars will demand electricity and how much of electricity will be needed for a specific time period asks specific information. This information are maximum share of cars during peak demand (0,2), capacity of grid to battery connection, share of parked cars grid connected (0,7), efficiencies of grid to battery and battery to grid (0,9), battery capacity.

Most of this information was taken from the EnergyPlan documentation (Lund, 2017). The rest, such as batter battery capacity was calculated assuming that 12 million cars average battery capacity is 20 kWh and 30% of these cars are available to charge/discharge (IEC, n/a). It resulted that the available battery capacity of 12 million V2G cars is equal to 72 GWh.

5.2.2 HP

In the heating sector, individual HP capacity will be expanded, while large-scale HP will be added to this model (reference scenario didn't had large-scale HP). The number of HP will be doubled, 5 million HP will be added in this model. 10 million of individual HP is almost half of the total heating demand. The increased heat production from HP will take the same share from oil-fired and gas-fired boilers (Table 2).

Individual heating	Reference scenario, TWh year	HP scenario, TWh, year	Change, TWh/year
Coal boilers	0	0	0
Oil boilers	43,76	0	-43,76
Ngas boilers	218,45	141,95	-76,50
Biomass boilers	54,60	54,60	0
HP	120	240	120

Table 2: The changes in individual heating after expanding HP capacity

Indeed, boilers based on coal will be totally removed from the system. For group 3 (central CHP plants) 3000 large-scale HP supply will be included. This number represents the predicted heat production by 2030 of this technology (Irena, 2015).

5.2.3 Storage

In the next model, HP and CHP heat units will be connected to the hot water tanks. Assuming that one house will contain optimal size of thermal storage equal to 100l, the total capacity of thermal storage for 10 million HP will be 87,7 TWh/year.

Both HP and CHP in group 3 will have a capacity of hot water tanks equal to 286 GWh energy, while group CHP plants due to the small number, will contain only 5,1 GWh.

The storage capacity for individual, large-scale HP and CHP units were calculated according to these assumptions:

- 1m3 of stored water in thermal storage has contains 87,7 kWh of energy (Energy storage)
- Optimal storage capacity for a typical house is 100l (Danish Energy Agency)
- The optimal thermal storage capacity for 1 MWel CHP unit is 125m3 (Streckiene, G., Martinaitis, V., 2009

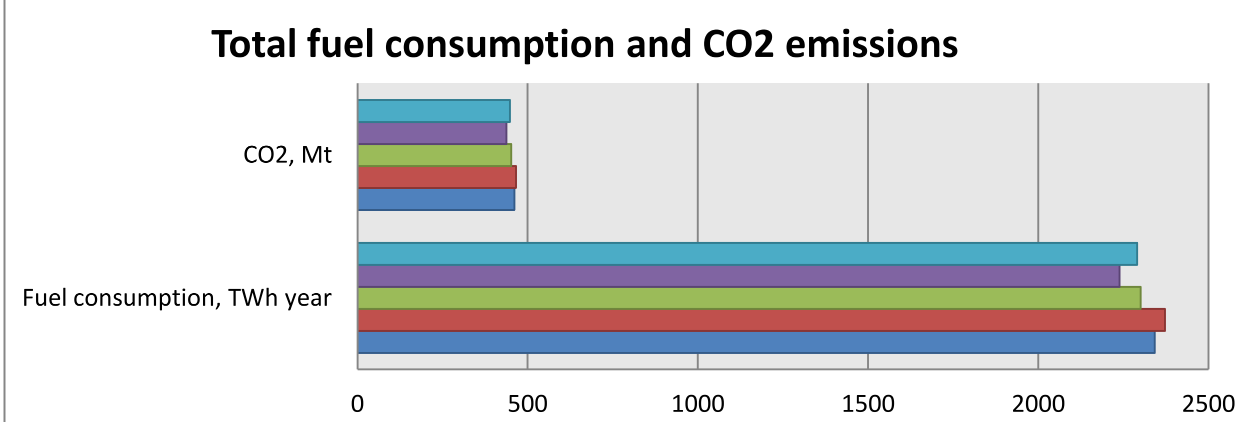
Finally, the last model of cross-section scenarios will contain all above mentioned added capacities of V2G, HP and Storage. The reason for this is to check how all the technologies work together, and if it can be the best model in terms of CO2 emissions and annual costs for the whole system.

6.0 Technical-economical analysis and the results

This chapter will graphically illustrate the outputs from all the simulated models of this study. Then different parameters will be compared, and finally the results will be analyzed to find out if cross-section excess electricity integration in different energy sectors can improve the reference scenario.

6.1 CO2 and total fuel consumption

The first two parameters are total fuel consumption and CO2 emissions (Figure 20). As it was mentioned in previous chapters, technical simulation is designed to find out the least fuel-consuming solution, which consequently leads to low CO2 emissions as well (Lund, 2017)



	Fuel consumption, TWh year	CO2, Mt
V2G+HP+Storage	2290.82	447.98
HP+Storage	2239.01	437.87
HP	2300.44	451.92
V2G	2372.09	465.56
Reference	2342.6	460.57

Figure 21: The fuel consumption and CO2 emissions comparison among reference scenario and cross-section scenarios

From this figure it can be seen that the most CO2 friendly **scenario is HP+Storage**. This reduction occurred for several reasons. Firstly, increased capacity of individual HP reduced the share of gas-fired and totally excluded oil-fired boilers.

Secondly, the introduction of large-scale HP into the model changed heat-only boilers, which were fed on natural gas (the technical simulation for heat-only boilers gives the last priority). And last but not the least, thermal storage capacity further reduced CO2 emissions and fuel consumption. To explain this, hot water tanks in technical simulation is used to minimize EEP and PP (Lund 2017). When PP electricity production drops, fuel consumption and CO2 emissions follow similar pattern as well. To illustrate this in numbers, compared to the **reference scenario** fuel usage of fuel and CO2 emissions in **HP+storage scenario** fall by **103,59 TWh/year** and **22,7 million tones** accordingly. Approximately for both parameters it is **a 5% reduction**.

In addition, table 3 shows which kind of fuel consumption for all five scenarios had increased and which had declined. The basic trends moving from **reference to the V2G+HP+Storage models** were that coal and biomass numbers grew up, oil and natural gas declined, while renewable remained almost stable. The coal numbers increased because after added new capacity, electricity demand went up, thus PP production as well. While oil and natural gas followed different pattern because added capacity of HP, V2G cars also changed boilers based on natural gas and oil, and cars based on oil. The least fuel-consumed **model with all technologies** saved **54,85 TWh/year** oil and **75,57 TWh/year** natural gas compared with the reference scenario.

	Coal	Oil	Natural Gas	Biomass	Renewables
Reference	301,51	574,29	907,99	250,46	308,35
V2G	320,53	544,14	940,83	258,24	308,36
HP	344,39	519,44	835,32	261,07	304,02
HP+Storage	327	519,44	832,42	260,89	304,02
V2G+HP+Storage	353	489,44	878,24	271,52	304,02

Table 3: Fuel balance for all the scenarios

One cross-section scenario had opposite trends that the rest of the models. Increased V2G cars had a negative impact for the fuel consumption and CO2 emissions. One of the reasons is that increased demand for electricity resulted in higher PP production (Figure 21).

6.2 Central power plants production

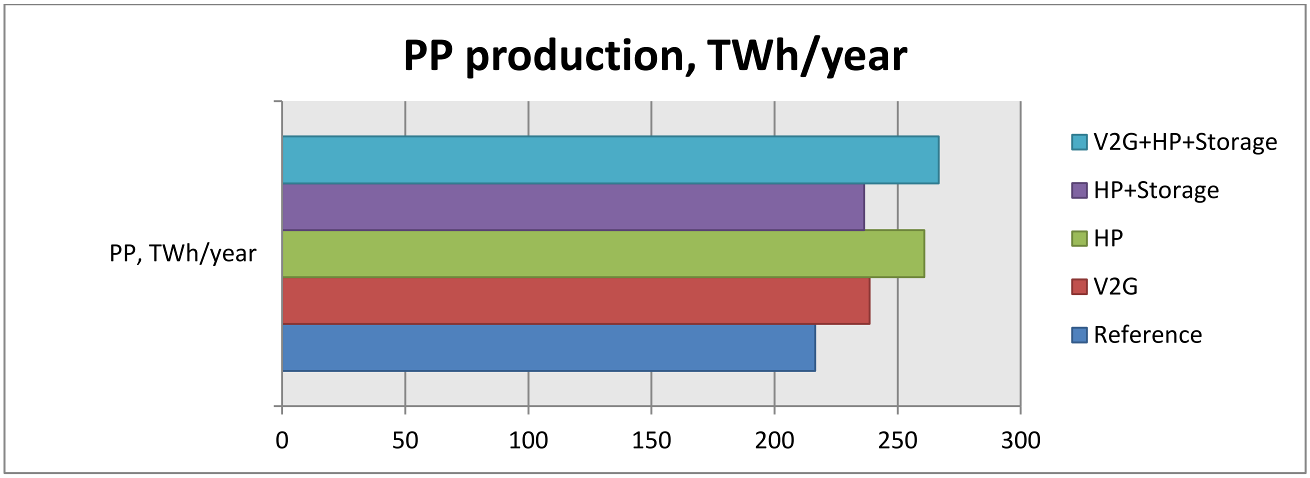


Figure 22: PP and CHP comparison among reference scenario and cross-section scenarios

The figure above shows that by adding extra capacity in the models, automatically PP generation in order to meet the increased electricity demand is growing, except in the model with the thermal storage (**HP+Storage**), where the electricity generation declined from PP.

However, the figure 21 doesn't explain the full picture when it comes to PP electricity production. For every new model different capacities of PP units were set in order to avoid warnings, such as grid stabilization problem or PP/import problem. In order to avoid these signals in EnergyPlan the user has either to expand transmission line capacity, PP production or increase the minimum share of large CHP and PP (Lund, 2017).

Table 4 illustrates that with the increasing electricity demand in order to keep the energy system stable, additional capacity of PP units are required, again except in **HP+Storage scenario**.

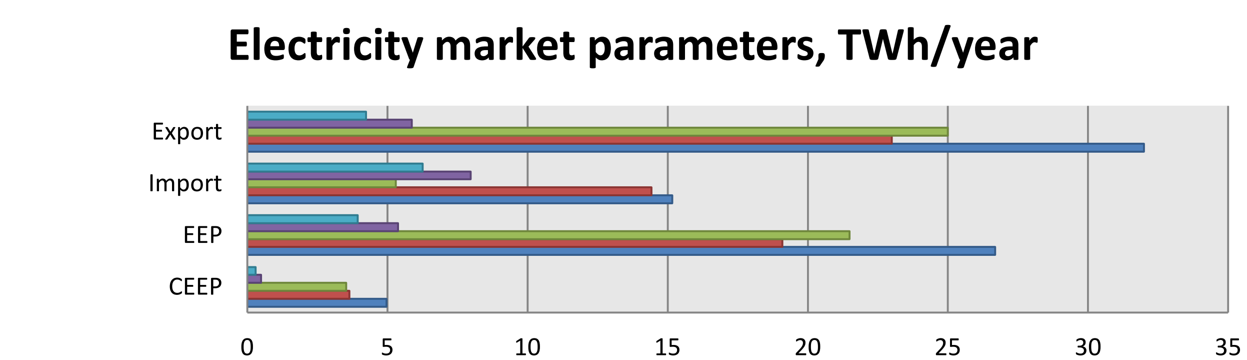
Scenarios	The capacity of PP units, MW
Reference scenario	52000
V2G	57000
HP	70000
HP+Storage	61000
V2G+HP+Storage	72000

Table 4: The capacity of PP units among reference scenario and cross-section scenarios

Moving from **reference scenario** to **scenario with all technologies** PP numbers were increased by 20000 MW. Considering that one 1 MW investment costs equal around 1 million EUR, it results that after added new capacity the model had **20000 million EUR** more expenses.

6.3 Electricity market parameters

One of the aims of designing cross-section models was to utilize EEP and CEEP. These parameters in reference scenario stood at **4,97 and 26,69 TWh/year**, while the electricity import/export numbers stood at **15,16 and 32 TWh/year** respectively (Figure 22).



	CEEP	EEP	Import	Export
V2G+HP+Storage	0.3	3.94	6.26	4.24
HP+Storage	0.49	5.38	7.97	5.87
HP	3.53	21.49	5.3	25
V2G	3.64	19.09	14.42	23
Reference	4.97	26.69	15.16	32

Figure 23: Electricity export/import, EEP, CEEP comparison among reference scenario and cross-section scenarios

All of the cross-section models were able to minimize electricity market criteria mentioned above in comparison to the reference scenario. The last two models, **HP+Storage** and **V2G+HP+Storage**, generally in all categories show the best results. For example, in the last model (**V2G+HP+Stroage**) the CEEP were almost eliminated, the figures fell from **4,97 to 0,30 TWh/ year**. The EEP production declined even more, **by 85%**, **from 26,69 to 3,94 TWh/year**. While the electricity import/export followed similar pattern as well. These mentioned numbers also could be illustrated by graph from EnergyPlan (Figure 23). It can be seen that when the electricity is utilized in domestic markets the velocity of EEP, CEEP and imports declines significantly.

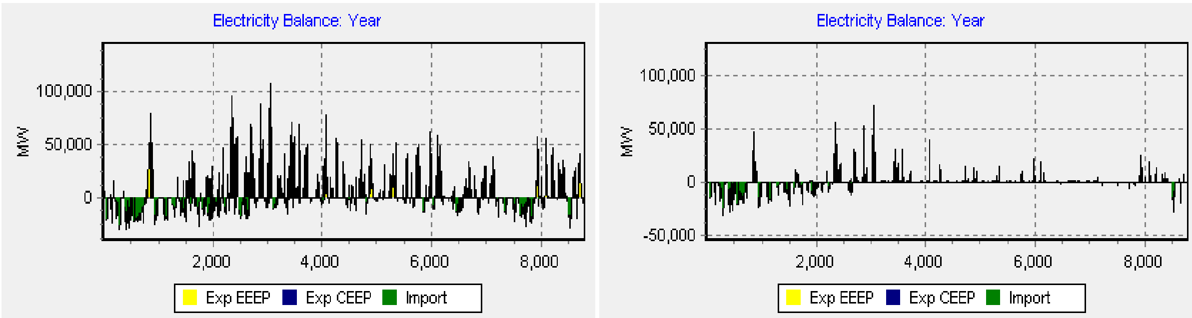
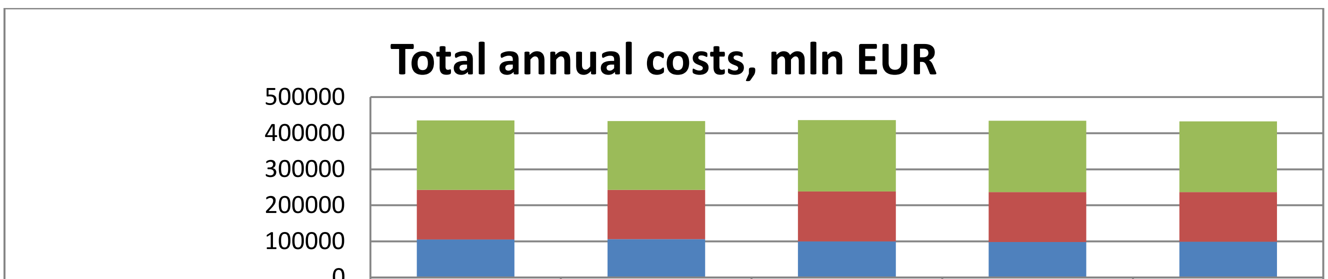


Figure 24: The comparison of EEP,CEEP and import parameters among reference and V2G+HP+Storage scenarios

6.4 Total annual costs

The last but not the least parameter to evaluate different models is total annual costs. It consists of total variable, fixed operation and annual investment costs (Figure 24).



	Reference	V2G	HP	HP+Storage	V2G+HP+Storage
Annual investments costs	192975	191053	198721	198298	196697
Fixed operation costs	137296	136722	138277	138004	137615
Total variable costs	105496	105993	99880	98387	99023

Figure 25: Total annual costs comparison among reference scenario and cross-section scenarios

Compared to the reference scenario, the lowest cost for the whole energy system was generated by the scenario where all three technologies are included, V2G, HP and thermal storage. This scenario total costs stand at **433336 million EUR**, while the reference scenario had **435767 million EUR costs**, the **difference of 2431 million EUR**. The cheapest model in terms of the lowest total annual costs was followed by V2G, HP+Storage, Reference and HP scenarios.

Annual investments costs grew in all cross-section models, while total variable costs declined, except for V2G scenario. This can be explained that new investments to more advanced technologies are more expensive but total variable costs (which mostly are fuel) are lower. The V2G had shown opposite trends because it is predicted that investments costs by 2030 to buy EVs will be cheaper than cars which uses fossil fuel.

7.0 Sensitivity Analysis

This chapter will further simulate cross-section, V2G+HP+Storage scenario, in order to find out how the parameters of energy system will be changed compared to the reference scenario if different prices and different capacities will be tested.

7.1 Price reduction

In recent decade, the price of new technologies gets cheaper and develops faster than different institutions had predicted in the past. Therefore, it can be considered as a valid argument to use this indicator for the first part of sensitivity analysis to check how much the total annual costs for the whole energy system in Germany will be reduced if the costs for EVs and HP will be reduced by 20% and 50% (Figure 24).

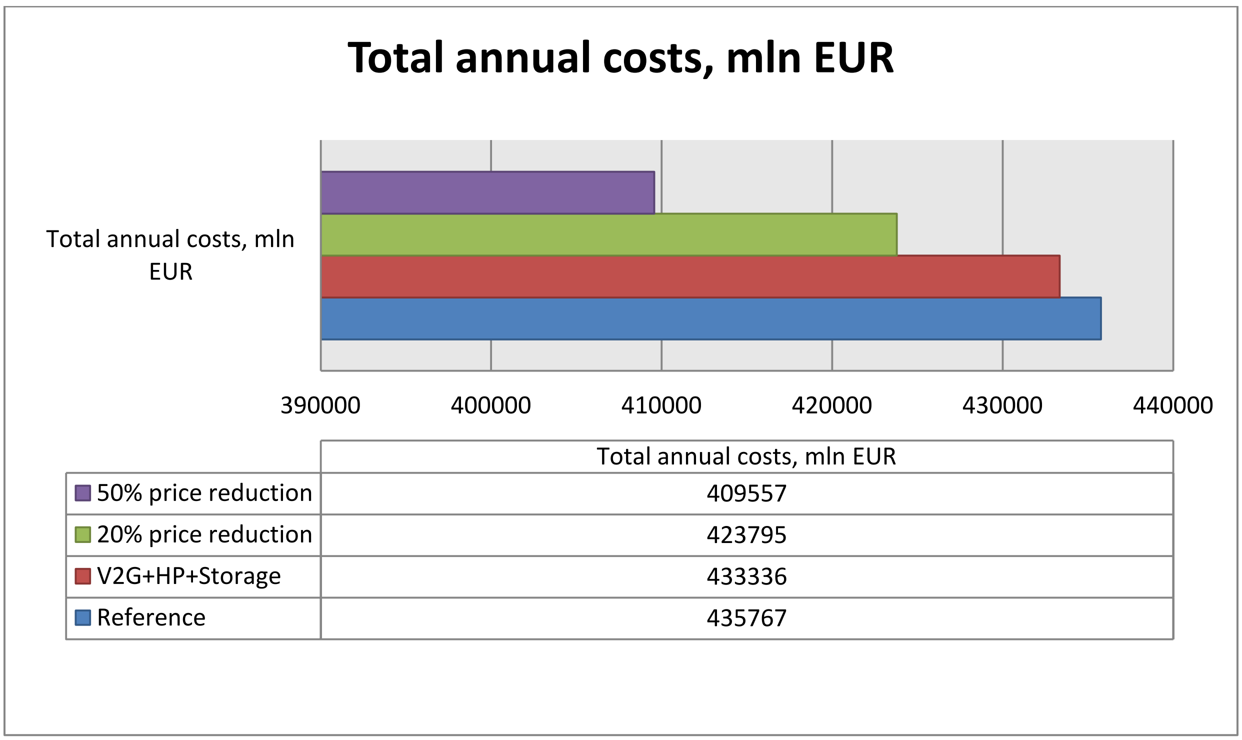


Figure 26: Total annual costs comparison among reference scenario, V2G+HP+Storage and 20%, 50% price reduction

The figure shows that the total annual costs after 50% and 20% price cut dropped by **10,16% and 3,8%** respectively compared to the reference scenario. Thus, if due to the economies of scale technologies will further develop, it can be expected that EEP integration into heating and transport sectors can become even more economically feasible.

7.2 Capacity expansion

The second part of the sensitivity analysis will test the feasibility of expanding HP and V2G cars capacity. The same as in previous part, capacities will be increased by 50% and 20%. In this part, after made adjustments, not only one parameter changed, like total annual costs in price reduction part, but changes were seen for the most of criteria (Table 4).

	Fuel consumption, TWh year	CO2, Mt	CEEP	EEP	Import	Export	Total Annual costs	PP, TWh/year	RES in primary energy, %	RES in electricity sector, %	Electricity production from RES, TWh/year	CHP, TWh/year
Reference	2342.6	460.57	4.97	26.69	15.16	32	435767	216.54	23.9	63.7	324.9	102.11
V2G+HP+Storage	2290.82	447.98	0.3	3.94	6.26	4.24	433336	266.73	25.1	60.7	322.6	110.63
20% capacity expansion	2291	**448.94**	0.13	2.59	4.74	2.71	**409192**	288.15	25.3	60.5	335.6	112.15
50% capacity expansion	2280	451.66	0.84	1.59	3.08	1.62	410928	321.7	25.5	60.2	340.2	113.7

Table 4: Different parameter comparison among reference scenario, V2G+HP+Storage and 20%, 50% capacity expansion for HP and V2G cars

From the table 4 it can be seen that the 20% capacity expansion at least in terms of CO2 emissions and total annual costs shows better results that 50% capacity expansion scenario. Compared with the reference scenario, the cost was lower by **25,575 million EUR.** This comparison proves that there are some economical limits to expand specific technology in the system.

8.0 Discussion

This chapter will discuss the limitations of the chosen approach used to solve the outlined problems in this study. Different considerations will be given to question the validity of the generated results from the simulated models. Next, the proposals for the future studies will be suggested.

8.1 Validity

The basic idea of this study was to build a reference scenario and the try to improve it by building alternative models, which slightly different energy systems. To do that, the data for building these scenarios was taken from different studies. Taking into account that these studies were made for future energy systems as well, it can be assumed that a lot of uncertainty already exists in this project. Furthermore, inserted data was digested by EnergyPlan software and then the results were generated. These results were determined by many factors, but probably most important is simulation strategy. Technical simulation over market-economic simulation for already explained reasons in previous chapters was chosen. However, in real life energy systems don't work in closed systems. It can be argued, that without operating electricity market, the validity of the results of this study can be questionable. Moreover, counter arguments could be given that when technologies were added separately, market-economic simulation could be used to compare different technologies individually. With market-economic solution the least-cost solution would be found for every technology, but not for the whole system.

The next point for discussion is the reference scenario. Instead of being made business as usual case, the reference scenario basically was designed in a way which already would meet all climate and goals targets. On top of that, this model (except high numbers of EVs) already contains high numbers of RES. Thus, it was hard to find new ways how significantly further improve the outputs. Despite that, this study was able to prove that cross-section integration could further, even though insignificantly, produce better results. And again, the reason for the choice of the reference scenario with high share of RES is because is more realistic considering how fast the prices to install new technologies is falling down, and how fast technologies improves.

8.2 Future studies

This study aimed to reduce CO_2 emissions, CEEP and costs for the whole system only by using few technologies. If the boundaries would be expanded than more tools will be available to solve the same problems. One tool or technology, and probably most realistic until 2030, would be to expand DH and CHP systems. In this project analysis section it was seen that at times when back up capacity (mostly PP) had to cover electricity demand, most of the fossil fuel were used.

Therefore, increased number of CHP would increase energy efficiency, and less fuel for the whole system would be consumed. However, the technical-economic calculations need to be made to find out if it is worth to invest into new DH infrastructure.

In transport sector probably the alternative to cars which run on fossil fuel will not be one silver bullet solution. But rather few alternative technologies will play some part in the future sustainable transport development (Lewe, H-U). Thus, next studies, besides the electrification described in this project, could investigate the further feasibility of biofuels, hydrogen or other synthetic fuels. First, hydrogen production could be almost carbon neutral and second the price of electricity could drop further, thus this technology could become more competitive. The other option is to explore possibilities for different synthetic fuels. This fuel had a big advantage because the fuel can directly be used in combustion engines, and no additional investment is needed. Considering the fact that most of the car park currently is running on combustion engines, synthetic fuels could play an important role to help reduce GHG emissions.

This study was able to minimize CO2 emissions. But if the new study would be needed to find out the most cost-effective way to do that until 2030, probably it would be the coal power plant fuel conversion to natural gas (Lewe, H-U).

Germany, the same as EU, imports vast amounts of fossil fuel from outside the EU borders (mainly Russia). This study proved that is possible to save fossil fuel. The future studies could calculate how much less fossil fuel would be needed to import, and how much money Germany would save. In addition, different study could calculate how much value is created when is investing in domestic markets and sustainable technologies are installed. The value could be measured in job creation, less pollution, lower health costs etc.

9.0 Conclusion

The present study had examined energy system in Germany where the growing share of two particular technologies, wind and solar PV, will be the backbone of energy production in the future. This project took a different approach how to deal with the overproduction of the electricity from intermittent RES sources. Instead of focusing on expanding interconnector's capacity to neighboring countries, the surplus electricity production was integrated into heat and transport sectors. Three technologies, HP, TS and V2G cars, had been employed for this task. They applicability were determined by a few number of studies and theories, which stresses that these technologies in particular are relevant to use for cross-section integration in the period set in this study.

However, to change the direction of the electricity flow was not the main aim of this study. At the beginning of this work also few problems were outlined, one of them is CO2 emissions, which directly can be linked to the fossil fuel consumption. This problem basically determined that in Energyplan software, technical simulation strategy was chosen, which optimizes the energy production in a way that the least fuel is used. The second outlined parameter was the cost for the whole system. This is based on the assumption that energy production in future energy systems will increasingly be shift from centralized systems based on fossil fuel to the decentralized systems based on RES. This transformation definitely will have significant costs. To put into this study context, the socio-economic feasibility was tested if the benefits of expanding RES capacity and then integrating some amount of surplus electricity domestically can be also a cost-effective solution.

And the best way to find out if the studies goals were implemented is to answer the research question:

To what extent cross-sector excess electricity integration into heating and transport sectors could reduce the CO2 emissions and the costs for the whole energy system in Germany by 2030?

According to the results for the CO2 emissions and total annual costs, it can be concluded that basically almost all energy models showed better results that the reference scenario (Table 5).

Scenarios	CO2 emissions, Mln,t	Total annual costs, Mln EUR	EEP, TWh/year	CEEP, TWh/year
Reference	460,57	435767	26,69	4,97
V2G	465,56	433368	19,09	3,64
HP	451,92	436877	21,49	3,53
HP+Storage	**437,87**	434689	5,38	0,49
V2G+HP+Storage	447,98	433336	3,94	0,3
20% price reduction	447,98	423795	3,94	0,3
50% price reduction	447,98	409557	3,94	0,3
20% capacity expansion	448,94	**409192**	2,59	0,13
50% capacity expansion	451,66	410928	**1,59**	**0,04**

Table 5: The final comparison of CO2 emissions and total annual costs among all the scenarios made in the study

The best results for CO2 emissions and the total costs were generated by **HP+Storage and 20% capacity expansion respectively**. This proves, that heat sector in particular could play an important role to meet Germans climate goals, considering the fact that currently most of the heating is based on inefficient energy units fed on fossil fuel.

Table 5 also confirms that if the capacity increased, technologies are able to utilize overproduction of electricity. And consequently, the electricity markets parameters, such as EEP and CEEP falls accordingly. This situation can benefit Germany energy system in different ways. First, reduced amount of EEP means that instead of exported electricity at the cheap price neighboring countries, integrated domestically could have a bigger value economically. In most cases to import electricity, due to simply laws of demand and supply, cost more than to export. Secondly, reduced number of CEEP gives promises in the future, that cross-section integration could play a part in the planning of future grid systems to avoid the bottlenecks.

Overall, this study had showed from different angles that cross-section electricity integration can have positive effects on future energy system in Germany. And together with other flexibility measures can be a solution to balance electricity production from solar PV and wind power.

Bibliography

Agora Energiewende, 2015 (a). Understanding the Energiewende.

Available online at: https://www.agora-energiewende.de/fileadmin2/Projekte/2015/Understanding_the_EW/Agora_Understanding_the_Energiewende.pdf

Irena, 2015. Renewable energy prospects, Germany.

Available online at: http://www.irena.org/publications/2015/Nov/Renewable-Energy-Prospects-Germany

AG Energiebilanzen, 2017.

Available online at: https://ag-energiebilanzen.de/6-0-Primaerenergieverbrauch.html

Agora Energiewende, 2015 (b). Report on the German power system.

Avialable online at: https://www.agora-energiewende.de/fileadmin/downloads/publikationen/CountryProfiles/Agora_CP_Germany_web.pdf

Agora Energiewende, 2017. Heat transition 2030. Key technologies for reaching the intermediate and long-term climate targets in the building sector

Available online at: https://www.agora-energiewende.de/fileadmin/Projekte/2016/Sektoruebergreifende_EW/Heat-Transition-2030_Summary-WEB.pdf

Agora Energiewende, 2018. Energiewende 2030-The Big Picture.

Available online at: https://www.agora-energiewende.de/fileadmin2/Projekte/2017/Big_Picture/134_Big-Picture_EN_WEB.pdf

Cleanenergywire. Auctions bring solar power price to new record low.

Available online at: https://www.cleanenergywire.org/news/auctions-bring-german-solar-power-price-new-record-low

IEC, n/a. Electrical Energy Storage.

Available online at: http://www.iec.ch/whitepaper/pdf/iecWP-energystorage-LR-en.pdf

Mathiesen, Lund, 2015. Mathiesen BV, Lund H, Connolly D, Wenzel H, Østergaard PA, M€oller B, et al. Smart energy systems for coherent 100% renewable energy and transport solutions. Appl Energy 2015;145:139e54.

Availabline online at: http://dx.doi.org/10.1016/j.apenergy.2015.01.075.

Agora Energiewende, 2014. Electricity Storage in the German Energy Transition.

Available online at: https://www.agora-energiewende.de/fileadmin/Projekte/2013/speicher-in-der-energiewende/Agora_Speicherstudie_EN_web.pdf

Lund, Østergaard, 2016. Energy Storage and Smart Energy Systems

Available online at: https://journals.aau.dk/index.php/sepm/article/view/1574

Lund, 2017. EnergyPlan. Advanced Energy System Analysis Computer Model.

Availabe online at: http://www.energyplan.eu/wp content/uploads/2017/11/documentation.pdf

Connolly, Lund, 2010. Connolly D, Lund H, Mathiesen BV, Leahy M. Modelling the existing Irish energy-system to identify future energy costs and the maximum wind penetration feasible. Energy 2010;35(5):2164e73.

Availabe online at: https://www.sciencedirect.com/science/article/pii/S0360544210000484?via%3Dihub

Connolly, 2015. Finding and Inputting Data into EnergyPlan

Available online at: http://www.energyplan.eu/wp-content/uploads/2013/06/Finding-and-Inputting-Data-into-the-EnergyPLAN-Tool-v5.pdf

Thellufsen, Lund, 2017. Thellufsen, J., S., Lund, H. Cross-border versus cross-sector interconnectivity in renewable energy systems. Energy. Volume 124, 1 April 2017, Pages 492-501

Available online at: https://www.sciencedirect.com/science/article/pii/S0360544217302943?via%3Dihub

Krajacic, Duic, 2011. Krajacic, G., Duic, N., Zmijarevic, Z., Mathiesen, B., V., Vucininic, A., V., Carvalho. M., G.Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO2 emissions reduction. Applied Thermal Engineering 31 (2011) 2073-2083.

Available online at: https://www.sciencedirect.com/science/article/pii/S1359431111001463

Lund, 2005. Lund, H. Large-scale integration of wind power into different energy systems. Energy 2005;30:2402e12.

Available online at: http://dx.doi.org/10.1016/j.energy.2004.11.001

Agora Energiewende, 2014. Electricity Storage in the German Energy Transition.

Available online at: https://www.agora-energiewende.de/fileadmin/Projekte/2013/speicher-in-der-energiewende/Agora_Speicherstudie_EN_web.pdf

Connolly, D., Lund, H., 2013. Holistic and Integrated Energy Systems for the era of 100% Renewable Energy.

Available online at: http://vbn.aau.dk/files/78422810/Smart_Energy_Systems_Aalborg_University.pdf

IEA, 2016. The role of electricity storage in the German energy system of the future

Available online at: https://www.iea.org/media/workshops/2016/energystorageeuwp/TheroleofelectricitystorageintheGermanenergysystemofthefuture.pdf

Lund, Østergaard, 2016. Energy Storage and Smart Energy Systems

Available online at: https://journals.aau.dk/index.php/sepm/article/view/1574

Energinet, 2018. Technology Data for Energy Plants for Electricity and District heating generation.

Available online at: https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_energy_plants_el_and_dh_-_aug_2016_update_march2018.pdf

Mathiesen, Lund, 2009. Mathiesen BV, Lund H. Comparative analyses of seven technologies to facilitate the integration of fluctuating renewable energy sources. IET RenewPower Gen 2009/6;3:190–204.

Bloomberg New Energy Finance. Flexibility and Power Market design

Availabe online at: https://about.bnef.com/future-energy-summit/new-york-videos/?vid=263981217

Averfalk, Ingvarsson, 2017. Averfalk, H., Ingvarsson, U., Persson, U., Gong, M., Werner, S., (2017). Large heat pumps in Swedish district heating systems.

Available online at: http://www.sciencedirect.com/science/article/pii/S1364032117307839

DAE, 2016. Technology Data for Individual Heating Plants and Energy Transport

https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_individual_heating_plants_october_2017.pdf

Mathiesen, Hansen, 2017. Mathiesen, B., V., Hansen, K. The role of Solar thermal in Future Energy Systems

Available online at: http://vbn.aau.dk/files/265304574/IEA_SHC_Task_52_STA_AAU_report_20170914.pdf

BluePrint Germany, 2009. A Strategy for a Climate Safe 2050.

Available online at: http://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/WWF_Blueprint_Germany.pdf

World Wild Fund, 2017. Germany's Electric Future. Coal phase-out 2035.

Available online at: https://www.oeko.de/fileadmin/oekodoc/Coal-phase-out-2035.pdf

EnergyPLan, costdatabase.

Available online at: http://www.energyplan.eu/resourcesbycountry/

Output specifications Reference scenario.txt The EnergyPLAN model 13.0

District Heating Production

	Gr.1				Gr.2										Gr.3										RES specification				
	District heating MW	Solar MW	CSHP MW	DHP MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW	RES1 Wind GW	RES2 Photo \ GW	RES3 Offshoı GW	RES 4-7 ind GW	Total GW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33353	18	0	20612	0	0	12622	0	0	101	14	1	7	0	22
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31517	34	0	18613	0	0	11965	0	0	905	21	3	9	0	33
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26483	71	0	19200	0	0	7139	0	0	74	12	8	4	0	24
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18838	100	0	14664	0	0	4074	0	0	0	14	12	7	0	33
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3829	106	0	3451	0	0	273	0	0	0	11	13	7	0	31
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	95	0	2357	0	0	209	0	0	0	9	9	6	0	25
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	77	0	2383	0	0	201	0	0	0	13	8	7	0	28
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	84	0	2341	0	0	236	0	0	0	10	8	7	0	25
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	78	0	2415	0	0	168	0	0	0	11	8	7	0	26
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	54	0	2525	0	0	81	0	0	0	15	5	8	0	28
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19496	27	0	15005	0	0	4373	0	0	92	12	2	8	0	22
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31352	12	0	15576	0	0	14586	0	0	1178	31	1	12	0	44
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14800	63	0	9895	0	0	4647	0	0	194	14	6	8	0	28
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51659	434	0	21303	0	0	26000	0	0	17115	91	86	20	0	127
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	130.00	0.55	0.00	86.92	0.00	0.00	40.82	0.00		1.70	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		54628
Uranium =	0	
Coal =	3473	
FuelOil =	924	
Gasoil/Diesel=	21831	
Petrol/JP =	16495	
Gas handling =	4405	
Biomass =	7499	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		32436
Marginal operation costs =		1015
Total Electricity exchange =		1481
Import =	679	
Export =	-1423	
Bottleneck =	216	
Fixed imp/ex=	2009	
Total CO2 emission costs =		15936
Total variable costs =		105496
Fixed operation costs =		137296
Annual Investment costs =		192975
TOTAL ANNUAL COSTS =		435767

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	14849	32526	30999	64223	0	16902	159500	0	0	0	0	0	0	159500	159500	0
February	14076	29372	29984	59012	0	16902	149348	0	0	0	0	0	0	149348	149348	0
March	8398	30298	29992	45523	0	16902	131113	0	0	0	0	0	0	131113	131113	0
April	4793	23139	30247	29185	0	16902	104267	0	0	0	0	0	-876	105142	105142	0
May	321	5446	42673	4339	0	16902	69681	0	0	0	0	0	-30881	100562	100562	0
June	246	3719	41390	2262	0	16902	64520	0	0	0	0	0	-3516	68036	68036	0
July	236	3761	44168	2458	0	16902	67526	0	0	0	0	0	0	67526	67526	0
August	277	3694	42599	2575	0	16902	66047	0	0	0	0	0	0	66047	66047	0
September	197	3811	48201	2900	0	16902	72011	0	0	0	0	0	0	72011	72011	0
October	96	3984	42574	3313	0	16902	66870	0	0	0	0	0	0	66870	66870	0
November	5144	23678	36235	36218	0	16902	118177	0	0	0	0	0	22224	95952	95952	0
December	17160	24579	19955	60837	0	16902	139433	0	0	0	0	0	13623	125810	125810	0
Average	5467	15615	36594	25983	0	16902	100562	0	0	0	0	0	0	100562	100562	0
Maximum	30588	33617	76772	102125	0	16902	223273	0	0	0	0	0	80090	223273	223273	0
Minimum	0	0	0	0	0	16902	30273	0	0	0	0	0	-66253	30273	30273	0
Total for the whole year TWh/year	48.03	137.16	321.45	228.23	0.00	148.47	883.34	0.00	0.00	0.00	0.00	0.00	0.00	883.34	883.34	0.00

RES Share: 23.9 Percent of Primary Energy 63.7 Percent of Electricity 324.9 TWh electricity from RES 01-June-2018 [08:19]

Output specifications Reference scenario+V2G.txt The EnergyPLAN model 13.0

District Heating Production

	Gr.1				Gr.2										Gr.3										RES specification				
	District heating MW	Solar MW	CSHP MW	DHP MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW	RES1 Wind GW	RES2 Photo \ GW	RES3 Offsho GW	RES 4-7 ind GW	Total GW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33353	18	0	20612	0	0	12622	0	0	101	14	1	7	0	22
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31517	34	0	18613	0	0	11965	0	0	905	21	3	9	0	33
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26483	71	0	19200	0	0	7139	0	0	74	12	8	4	0	24
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18838	100	0	14664	0	0	4074	0	0	0	14	12	7	0	33
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3829	106	0	3451	0	0	273	0	0	0	11	13	7	0	31
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	95	0	2357	0	0	209	0	0	0	9	9	6	0	25
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	77	0	2383	0	0	201	0	0	0	13	8	7	0	28
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	84	0	2341	0	0	236	0	0	0	10	8	7	0	25
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	78	0	2415	0	0	168	0	0	0	11	8	7	0	26
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	54	0	2525	0	0	81	0	0	0	15	5	8	0	28
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19496	27	0	15005	0	0	4373	0	0	92	12	2	8	0	22
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31352	12	0	15576	0	0	14586	0	0	1178	31	1	12	0	44
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14800	63	0	9895	0	0	4647	0	0	194	14	6	8	0	28
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51659	434	0	21303	0	0	26000	0	0	17115	91	86	20	0	127
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	130.00	0.55	0.00	86.92	0.00	0.00	40.82	0.00		1.70	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		52982
Uranium =	0	
Coal =	3692	
FuelOil =	924	
Gasoil/Diesel=	21831	
Petrol/JP =	14358	
Gas handling =	4453	
Biomass =	7723	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		33642
Marginal operation costs =		1074
Total Electricity exchange =		1786
Import =	648	
Export =	-1030	
Bottleneck =	158	
Fixed imp/ex=	2009	
Total CO2 emission costs =		16108
Total variable costs =		105593
Fixed operation costs =		136722
Annual Investment costs =		191053
TOTAL ANNUAL COSTS =		433368

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	14849	32526	36367	64223	0	16902	164868	0	0	0	0	0	0	164868	164868	0
February	14076	29372	34309	59012	0	16902	153672	0	0	0	0	0	0	153672	153672	0
March	8398	30298	34304	45523	0	16902	135425	0	0	0	0	0	0	135425	135425	0
April	4793	23139	33213	29185	0	16902	107233	0	0	0	0	0	-959	108191	108191	0
May	321	5446	45434	4339	0	16902	72442	0	0	0	0	0	-31859	104301	104301	0
June	246	3719	44945	2262	0	16902	68075	0	0	0	0	0	-2422	70497	70497	0
July	236	3761	47264	2458	0	16902	70621	0	0	0	0	0	0	70621	70621	0
August	277	3694	45923	2575	0	16902	69372	0	0	0	0	0	0	69372	69372	0
September	197	3811	51972	2900	0	16902	75782	0	0	0	0	0	0	75782	75782	0
October	96	3984	46207	3313	0	16902	70503	0	0	0	0	0	0	70503	70503	0
November	5144	23678	40948	36218	0	16902	122890	0	0	0	0	0	22950	99941	99941	0
December	17160	24579	23042	60837	0	16902	142520	0	0	0	0	0	12921	129599	129599	0
Average	5467	15615	40334	25983	0	16902	104301	0	0	0	0	0	0	104301	104301	0
Maximum	30588	33617	80576	102125	0	16902	230695	0	0	0	0	0	82011	230695	230695	0
Minimum	0	0	0	0	0	16902	20841	0	0	0	0	0	-83460	20964	20964	0
Total for the whole year TWh/year	48.03	137.16	354.29	228.23	0.00	148.47	916.18	0.00	0.00	0.00	0.00	0.00	0.00	916.18	916.18	0.00

RES Share: 23.9 Percent of Primary Energy 60.6 Percent of Electricity 327.8 TWh electricity from RES 01-June-2018 [08:24]

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage MW	Gr.3 Balance MW	RES1 Wind GW	RES2 Photo \ GW	RES3 Offshoı GW	RES 4-7 ind GW	Total GW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33353	18	0	21021	7457	0	4857	0	0	0	14	1	7	0	22
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31517	34	0	19865	6894	0	4693	0	0	30	21	3	9	0	33
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26483	71	0	19963	5035	0	1414	0	0	0	12	8	4	0	24
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18838	100	0	15515	2633	0	590	0	0	0	14	12	7	0	33
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3829	106	0	3498	138	0	88	0	0	0	11	13	7	0	31
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	95	0	2367	111	0	88	0	0	0	9	9	6	0	25
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	77	0	2399	104	0	81	0	0	0	13	8	7	0	28
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	84	0	2363	124	0	90	0	0	0	10	8	7	0	25
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	78	0	2426	88	0	68	0	0	0	11	8	7	0	26
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	54	0	2540	40	0	26	0	0	0	15	5	8	0	28
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19496	27	0	15576	2902	0	991	0	0	0	12	2	8	0	22
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31352	12	0	18794	7498	0	5048	0	0	0	31	1	12	0	44
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14800	63	0	10493	2744	0	1497	0	0	2	14	6	8	0	28
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51659	434	0	21303	9000	0	26000	0	0	3546	91	86	20	0	127
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	130.00	0.55	0.00	92.17	24.10	0.00	13.15	0.00		0.02	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		50957
Uranium =	0	
Coal =	3967	
FuelOil =	924	
Gasoil/Diesel=	18073	
Petrol/JP =	16484	
Gas handling =	3503	
Biomass =	8004	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		30843
Marginal operation costs =		1147
Total Electricity exchange =		1297
Import =	240	
Export =	-1101	
Bottleneck =	148	
Fixed imp/ex=	2009	
Total CO2 emission costs =		15637
Total variable costs =		99880
Fixed operation costs =		138277
Annual Investment costs =		198721
TOTAL ANNUAL COSTS =		436877

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	5714	33172	52938	41133	0	16902	149859	0	0	0	0	0	0	149859	149859	0
February	5522	31348	44816	37244	0	16902	135831	0	0	0	0	0	0	135831	135831	0
March	1664	31501	44909	27683	0	16902	122659	0	0	0	0	0	-152	122811	122811	0
April	694	24483	38953	17490	0	16902	98523	0	0	0	0	0	-1521	100044	100044	0
May	103	5520	44748	2660	0	16902	69933	0	0	0	0	0	-25689	95622	95622	0
June	103	3735	42418	1357	0	16902	64516	0	0	0	0	0	-8078	72594	72594	0
July	96	3786	45569	1473	0	16902	67826	0	0	0	0	0	0	67826	67826	0
August	105	3729	43885	1586	0	16902	66208	0	0	0	0	0	188	66020	66020	0
September	80	3828	50469	1804	0	16902	73084	0	0	0	0	0	-152	73236	73236	0
October	31	4009	44240	2073	0	16902	67254	0	0	0	0	0	-41	67295	67295	0
November	1166	24579	48221	22824	0	16902	113692	0	0	0	0	0	21405	92287	92287	0
December	5939	29657	27996	39131	0	16902	119626	0	0	0	0	0	14416	105210	105210	0
Average	1761	16559	44083	16318	0	16902	95622	0	0	0	0	0	0	95622	95622	0
Maximum	30588	33617	99270	66362	0	16902	208764	0	0	0	0	0	82722	208764	208764	0
Minimum	0	0	0	0	0	16902	31008	0	0	0	0	0	-61317	31008	31008	0
Total for the whole year TWh/year	15.47	145.45	387.22	143.33	0.00	148.47	839.95	0.00	0.00	0.00	0.00	0.00	0.00	839.95	839.95	0.00

RES Share: 24.9 Percent of Primary Energy 64.1 Percent of Electricity 331.5 TWh electricity from RES 01-June-2018 [08:26]

Output specifications   Reference scenario+HP+Storage.txt   The EnergyPLAN model 13.0

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage GW	Gr.3 Balance MW	RES specification RES1 Wind GW	RES2 Photo \ GW	RES3 Offsho GW	RES 4-7 ind GW	Total GW
January	33353	18	0	21093	7457	0	4850	0	4	-66	14	1	7	0	22
February	31517	34	0	20036	6894	0	4608	0	39	-55	21	3	9	0	33
March	26483	71	0	20711	4410	0	1285	0	92	7	12	8	4	0	24
April	18838	100	0	16280	2027	0	314	0	130	117	14	12	7	0	33
May	3829	106	0	3808	267	0	0	0	262	-352	11	13	7	0	31
June	2661	95	0	2367	187	0	0	0	279	12	9	9	6	0	25
July	2661	77	0	2411	173	0	0	0	273	0	13	8	7	0	28
August	2661	84	0	2363	213	0	0	0	271	1	10	8	7	0	25
September	2661	78	0	2426	157	0	0	0	272	-1	11	8	7	0	26
October	2661	54	0	2540	66	0	0	0	272	0	15	5	8	0	28
November	19496	27	0	16063	2406	0	663	0	182	337	12	2	8	0	22
December	31352	12	0	18813	7518	0	4982	0	8	27	31	1	12	0	44
Average	14800	63	0	10708	2641	0	1387	0	174	1	14	6	8	0	28
Maximum	51659	434	0	21303	9000	0	25521	0	286	12861	91	86	20	0	127
Minimum	2661	0	0	0	0	0	0	0	0	-15578	0	0	0	0	1
Total for the whole year TWh/year	130.00	0.55	0.00	94.06	23.20	0.00	12.18	0.00		0.01	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		50613
Uranium =	0	
Coal =	3815	
FuelOil =	924	
Gasoil/Diesel=	18073	
Petrol/JP =	16484	
Gas handling =	3468	
Biomass =	7848	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		29962
Marginal operation costs =		1107
Total Electricity exchange =		1810
Import =	42	
Export =	-263	
Bottleneck =	21	
Fixed imp/ex=	2009	
Total CO2 emission costs =		15300
Total variable costs =		98791
Fixed operation costs =		138283
Annual Investment costs =		198779
TOTAL ANNUAL COSTS =		435853

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	5706	33286	43876	41133	0	16902	140903	0	0	0	0	0	0	140903	140903	0
February	5421	31617	41754	37244	0	16902	132939	0	0	0	0	0	0	132939	132939	0
March	1511	32682	42525	27683	0	16902	121304	0	0	0	0	0	-83	121387	121387	0
April	370	25690	33060	17490	0	16902	93512	0	0	0	0	0	-2494	96006	96006	0
May	0	6009	43241	2660	0	16902	68814	0	0	0	0	0	-24078	92892	92892	0
June	0	3735	42020	1357	0	16902	64015	0	0	0	0	0	-8841	72856	72856	0
July	0	3805	45111	1473	0	16902	67291	0	0	0	0	0	0	67291	67291	0
August	0	3729	43513	1586	0	16902	65730	0	0	0	0	0	241	65489	65489	0
September	0	3828	50119	1804	0	16902	72653	0	0	0	0	0	-181	72834	72834	0
October	0	4009	43914	2073	0	16902	66898	0	0	0	0	0	-67	66964	66964	0
November	780	25348	41482	22824	0	16902	107335	0	0	0	0	0	17307	90029	90029	0
December	5861	29687	23211	39131	0	16902	114793	0	0	0	0	0	18382	96411	96411	0
Average	1632	16897	41143	16318	0	16902	92892	0	0	0	0	0	0	92892	92892	0
Maximum	30025	33617	98328	66362	0	16902	206461	0	0	0	0	0	83770	206461	206461	0
Minimum	0	0	0	0	0	16902	28578	0	0	0	0	0	-59614	28578	28578	0
Total for the whole year TWh/year	14.33	148.42	361.40	143.33	0.00	148.47	815.96	0.00	0.00	0.00	0.00	0.00	0.00	815.96	815.96	0.00

RES Share: 25.1 Percent of Primary Energy   63.7 Percent of Electricity   329.5 TWh electricity from RES

01-June-2018 [14:26]

District Heating Production

	Gr.1				Gr.2										Gr.3										RES specification				
	District heating MW	Solar MW	CSHP MW	DHP MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age GW	Ba-lance MW	RES1 Wind GW	RES2 Photo \ GW	RES3 Offsho GW	RES 4-7 ind GW	Total GW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33353	18	0	21098	7471	0	4832	0	7	-66	14	1	7	0	22
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31517	34	0	20041	6900	0	4601	0	39	-59	21	3	9	0	33
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26483	71	0	20724	4402	0	1275	0	94	11	12	8	4	0	24
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18838	100	0	16333	1971	0	314	0	132	120	14	12	7	0	33
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3829	106	0	3852	222	0	0	0	259	-350	11	13	7	0	31
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	95	0	2367	198	0	0	0	276	1	9	9	6	0	25
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	77	0	2399	188	0	0	0	272	-3	13	8	7	0	28
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	84	0	2363	193	0	0	0	267	21	10	8	7	0	25
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	78	0	2426	156	0	0	0	262	0	11	8	7	0	26
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	54	0	2540	65	0	0	0	263	1	15	5	8	0	28
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19496	27	0	16061	2437	0	650	0	182	322	12	2	8	0	22
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31352	12	0	18867	7517	0	4925	0	14	31	31	1	12	0	44
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14800	63	0	10721	2636	0	1378	0	172	2	14	6	8	0	28
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51659	434	0	21303	9000	0	25465	0	286	12861	91	86	20	0	127
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	0	0	0	0	0	0	0	0	-14704	0	0	0	0	1
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	130.00	0.55	0.00	94.17	23.15	0.00	12.10	0.00		0.01	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		49007
Uranium =	0	
Coal =	4047	
FuelOil =	924	
Gasoil/Diesel=	18073	
Petrol/JP =	14358	
Gas handling =	3519	
Biomass =	8085	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		31234
Marginal operation costs =		1168
Total Electricity exchange =		2115
Import =	280	
Export =	-188	
Bottleneck =	13	
Fixed imp/ex=	2009	
Total CO2 emission costs =		15500
Total variable costs =		99023
Fixed operation costs =		137615
Annual Investment costs =		196697
TOTAL ANNUAL COSTS =		433336

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	5685	33293	56141	41133	0	16902	153154	0	0	0	0	0	0	153154	153154	0
February	5413	31624	47297	37244	0	16902	138480	0	0	0	0	0	0	138480	138480	0
March	1500	32702	46900	27683	0	16902	125688	0	0	0	0	0	0	125688	125688	0
April	369	25774	36780	17490	0	16902	97315	0	0	0	0	0	-2167	99483	99483	0
May	0	6078	45548	2660	0	16902	71189	0	0	0	0	0	-25645	96834	96834	0
June	0	3735	44941	1357	0	16902	66936	0	0	0	0	0	-7634	74570	74570	0
July	0	3786	47549	1473	0	16902	69710	0	0	0	0	0	0	69710	69710	0
August	0	3729	46146	1586	0	16902	68364	0	0	0	0	0	289	68074	68074	0
September	0	3828	53001	1804	0	16902	75535	0	0	0	0	0	-206	75742	75742	0
October	0	4009	46762	2073	0	16902	69745	0	0	0	0	0	-90	69835	69835	0
November	764	25344	42906	22824	0	16902	108740	0	0	0	0	0	14776	93964	93964	0
December	5794	29772	26987	39131	0	16902	118586	0	0	0	0	0	20831	97755	97755	0
Average	1621	16918	45075	16318	0	16902	96834	0	0	0	0	0	0	96834	96834	0
Maximum	29958	33617	102303	66362	0	16902	211536	0	0	0	0	0	84233	211536	211536	0
Minimum	0	0	0	0	0	16902	20913	0	0	0	0	0	-74147	20913	20913	0
Total for the whole year TWh/year	14.24	148.61	395.94	143.33	0.00	148.47	850.59	0.00	0.00	0.00	0.00	0.00	0.00	850.59	850.59	0.00

RES Share: 25.1 Percent of Primary Energy 60.7 Percent of Electricity 332.6 TWh electricity from RES

01-June-2018 [14:28]

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage GW	Gr.3 Balance MW	RES specification RES1 Wind GW	RES2 Photo \ GW	RES3 Offshoı GW	RES 4-7 ind GW	Total GW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33353	18	0	21098	7471	0	4832	0	7	-66	14	1	7	0	22
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31517	34	0	20041	6900	0	4601	0	39	-59	21	3	9	0	33
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26483	71	0	20724	4402	0	1275	0	94	11	12	8	4	0	24
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18838	100	0	16333	1971	0	314	0	132	120	14	12	7	0	33
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3829	106	0	3852	222	0	0	0	259	-350	11	13	7	0	31
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	95	0	2367	198	0	0	0	276	1	9	9	6	0	25
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	77	0	2399	188	0	0	0	272	-3	13	8	7	0	28
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	84	0	2363	193	0	0	0	267	21	10	8	7	0	25
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	78	0	2426	156	0	0	0	262	0	11	8	7	0	26
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	54	0	2540	65	0	0	0	263	1	15	5	8	0	28
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19496	27	0	16061	2437	0	650	0	182	322	12	2	8	0	22
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31352	12	0	18867	7517	0	4925	0	14	31	31	1	12	0	44
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14800	63	0	10721	2636	0	1378	0	172	2	14	6	8	0	28
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51659	434	0	21303	9000	0	25465	0	286	12861	91	86	20	0	127
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	0	0	0	0	0	0	0	0	-14704	0	0	0	0	1
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	130.00	0.55	0.00	94.17	23.15	0.00	12.10	0.00		0.01	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange = 49007
- Uranium = 0
- Coal = 4047
- FuelOil = 924
- Gasoil/Diesel= 18073
- Petrol/JP = 14358
- Gas handling = 3519
- Biomass = 8085
- Food income = 0
- Waste = 0

Total Ngas Exchange costs = 31234

Marginal operation costs = 1168

Total Electricity exchange = 2115
- Import = 280
- Export = -188
- Bottleneck = 13
- Fixed imp/ex= 2009

Total CO2 emission costs = 15500

Total variable costs = 99023

Fixed operation costs = 134962

Annual Investment costs = 189810

TOTAL ANNUAL COSTS = 423795

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	5685	33293	56141	41133	0	16902	153154	0	0	0	0	0	0	153154	153154	0
February	5413	31624	47297	37244	0	16902	138480	0	0	0	0	0	0	138480	138480	0
March	1500	32702	46900	27683	0	16902	125688	0	0	0	0	0	0	125688	125688	0
April	369	25774	36780	17490	0	16902	97315	0	0	0	0	0	-2167	99483	99483	0
May	0	6078	45548	2660	0	16902	71189	0	0	0	0	0	-25645	96834	96834	0
June	0	3735	44941	1357	0	16902	66936	0	0	0	0	0	-7634	74570	74570	0
July	0	3786	47549	1473	0	16902	69710	0	0	0	0	0	0	69710	69710	0
August	0	3729	46146	1586	0	16902	68364	0	0	0	0	0	289	68074	68074	0
September	0	3828	53001	1804	0	16902	75535	0	0	0	0	0	-206	75742	75742	0
October	0	4009	46762	2073	0	16902	69745	0	0	0	0	0	-90	69835	69835	0
November	764	25344	42906	22824	0	16902	108740	0	0	0	0	0	14776	93964	93964	0
December	5794	29772	26987	39131	0	16902	118586	0	0	0	0	0	20831	97755	97755	0
Average	1621	16918	45075	16318	0	16902	96834	0	0	0	0	0	0	96834	96834	0
Maximum	29958	33617	102303	66362	0	16902	211536	0	0	0	0	0	84233	211536	211536	0
Minimum	0	0	0	0	0	16902	20913	0	0	0	0	0	-74147	20913	20913	0
Total for the whole year TWh/year	14.24	148.61	395.94	143.33	0.00	148.47	850.59	0.00	0.00	0.00	0.00	0.00	0.00	850.59	850.59	0.00

RES Share: 25.1 Percent of Primary Energy 60.7 Percent of Electricity 332.6 TWh electricity from RES 01-June-2018 [14:33]

Output specifications 50% price reduction.txt The EnergyPLAN model 13.0

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage GW	Gr.3 Balance MW	RES1 Wind GW	RES2 Photo \ GW	RES3 Offsho GW	RES 4-7 ind GW	Total GW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33353	18	0	21098	7471	0	4832	0	7	-66	14	1	7	0	22
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31517	34	0	20041	6900	0	4601	0	39	-59	21	3	9	0	33
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26483	71	0	20724	4402	0	1275	0	94	11	12	8	4	0	24
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18838	100	0	16333	1971	0	314	0	132	120	14	12	7	0	33
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3829	106	0	3852	222	0	0	0	259	-350	11	13	7	0	31
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	95	0	2367	198	0	0	0	276	1	9	9	6	0	25
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	77	0	2399	188	0	0	0	272	-3	13	8	7	0	28
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	84	0	2363	193	0	0	0	267	21	10	8	7	0	25
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	78	0	2426	156	0	0	0	262	0	11	8	7	0	26
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	54	0	2540	65	0	0	0	263	1	15	5	8	0	28
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19496	27	0	16061	2437	0	650	0	182	322	12	2	8	0	22
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31352	12	0	18867	7517	0	4925	0	14	31	31	1	12	0	44
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14800	63	0	10721	2636	0	1378	0	172	2	14	6	8	0	28
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51659	434	0	21303	9000	0	25465	0	286	12861	91	86	20	0	127
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	0	0	0	0	0	0	0	0	-14704	0	0	0	0	1
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	130.00	0.55	0.00	94.17	23.15	0.00	12.10	0.00		0.01	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		49007
Uranium =	0	
Coal =	4047	
FuelOil =	924	
Gasoil/Diesel=	18073	
Petrol/JP =	14358	
Gas handling =	3519	
Biomass =	8085	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		31234
Marginal operation costs =		1168
Total Electricity exchange =		2115
Import =	280	
Export =	-188	
Bottleneck =	13	
Fixed imp/ex=	2009	
Total CO2 emission costs =		15500
Total variable costs =		99023
Fixed operation costs =		131008
Annual Investment costs =		179526
TOTAL ANNUAL COSTS =		409557

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	5685	33293	56141	41133	0	16902	153154	0	0	0	0	0	0	153154	153154	0
February	5413	31624	47297	37244	0	16902	138480	0	0	0	0	0	0	138480	138480	0
March	1500	32702	46900	27683	0	16902	125688	0	0	0	0	0	0	125688	125688	0
April	369	25774	36780	17490	0	16902	97315	0	0	0	0	0	-2167	99483	99483	0
May	0	6078	45548	2660	0	16902	71189	0	0	0	0	0	-25645	96834	96834	0
June	0	3735	44941	1357	0	16902	66936	0	0	0	0	0	-7634	74570	74570	0
July	0	3786	47549	1473	0	16902	69710	0	0	0	0	0	0	69710	69710	0
August	0	3729	46146	1586	0	16902	68364	0	0	0	0	0	289	68074	68074	0
September	0	3828	53001	1804	0	16902	75535	0	0	0	0	0	-206	75742	75742	0
October	0	4009	46762	2073	0	16902	69745	0	0	0	0	0	-90	69835	69835	0
November	764	25344	42906	22824	0	16902	108740	0	0	0	0	0	14776	93964	93964	0
December	5794	29772	26987	39131	0	16902	118586	0	0	0	0	0	20831	97755	97755	0
Average	1621	16918	45075	16318	0	16902	96834	0	0	0	0	0	0	96834	96834	0
Maximum	29958	33617	102303	66362	0	16902	211536	0	0	0	0	0	84233	211536	211536	0
Minimum	0	0	0	0	0	16902	20913	0	0	0	0	0	-74147	20913	20913	0
Total for the whole year TWh/year	14.24	148.61	395.94	143.33	0.00	148.47	850.59	0.00	0.00	0.00	0.00	0.00	0.00	850.59	850.59	0.00

RES Share: 25.1 Percent of Primary Energy 60.7 Percent of Electricity 332.6 TWh electricity from RES 01-June-2018 [14:34]

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage GW	Gr.3 Balance MW	RES1 Wind GW	RES2 Photo \ GW	RES3 Offshoı GW	RES 4-7 ind GW	Total GW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33353	18	0	21149	8520	0	3732	0	6	-66	14	1	7	0	22
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31517	34	0	20406	7843	0	3324	0	40	-90	21	3	9	0	33
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26483	71	0	20906	4703	0	759	0	88	43	12	8	4	0	24
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18838	100	0	16536	1881	0	237	0	161	83	14	12	7	0	33
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3829	106	0	3952	193	0	0	0	307	-421	11	13	7	0	31
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	95	0	2369	197	0	0	0	331	0	9	9	6	0	25
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	77	0	2406	171	0	0	0	327	7	13	8	7	0	28
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	84	0	2369	188	0	0	0	317	19	10	8	7	0	25
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	78	0	2429	152	0	0	0	312	2	11	8	7	0	26
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	54	0	2545	61	0	0	0	312	1	15	5	8	0	28
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19496	27	0	16238	2533	0	301	0	208	397	12	2	8	0	22
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31352	12	0	19648	8553	0	3120	0	22	20	31	1	12	0	44
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14800	63	0	10878	2908	0	952	0	203	-1	14	6	8	0	28
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51659	434	0	21303	10800	0	23362	0	343	10605	91	86	20	0	127
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2661	0	0	0	0	0	0	0	0	-14554	0	0	0	0	1
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	130.00	0.55	0.00	95.55	25.55	0.00	8.36	0.00		-0.01	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		48489
Uranium =	0	
Coal =	4273	
FuelOil =	924	
Gasoil/Diesel=	18073	
Petrol/JP =	13933	
Gas handling =	2969	
Biomass =	8316	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		30395
Marginal operation costs =		1229
Total Electricity exchange =		2112
Import =	216	
Export =	-119	
Bottleneck =	5	
Fixed imp/ex=	2009	
Total CO2 emission costs =		15533
Total variable costs =		97758
Fixed operation costs =		129385
Annual Investment costs =		182049
TOTAL ANNUAL COSTS =		409192

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	4391	33374	65387	26509	0	16902	146564	0	0	0	0	0	3637	142926	142926	0
February	3910	32202	53854	23701	0	16902	130569	0	0	0	0	0	0	130569	130569	0
March	893	32991	53269	16978	0	16902	121032	0	0	0	0	0	-70	121103	121103	0
April	279	26093	40180	10724	0	16902	94179	0	0	0	0	0	-2488	96667	96667	0
May	0	6236	45849	1666	0	16902	70653	0	0	0	0	0	-23582	94235	94235	0
June	0	3739	45549	842	0	16902	67032	0	0	0	0	0	-9373	76404	76404	0
July	0	3796	48313	913	0	16902	69925	0	0	0	0	0	7	69917	69917	0
August	0	3739	46754	1004	0	16902	68399	0	0	0	0	0	375	68024	68024	0
September	0	3833	53888	1146	0	16902	75769	0	0	0	0	0	-67	75836	75836	0
October	0	4016	47616	1325	0	16902	69860	0	0	0	0	0	-317	70177	70177	0
November	354	25623	49260	14445	0	16902	106584	0	0	0	0	0	14676	91908	91908	0
December	3670	31004	34564	25385	0	16902	111526	0	0	0	0	0	17291	94235	94235	0
Average	1120	17165	48695	10353	0	16902	94235	0	0	0	0	0	0	94235	94235	0
Maximum	27484	33617	112868	43711	0	16902	198722	0	0	0	0	0	79224	198722	198722	0
Minimum	0	0	0	0	0	16902	20723	0	0	0	0	0	-73415	20723	20723	0
Total for the whole year TWh/year	9.84	150.78	427.74	90.94	0.00	148.47	827.76	0.00	0.00	0.00	0.00	0.00	0.00	827.76	827.76	0.00

RES Share: 25.3 Percent of Primary Energy 60.5 Percent of Electricity 335.6 TWh electricity from RES 01-June-2018 [14:37]

Output specifications   50% HP and V2F capacity expansion.txt   The EnergyPLAN model 13.0

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage MW	Gr.2 Balance MW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage GW	Gr.3 Balance MW	RES specification RES1 Wind GW	RES2 Photo V GW	RES3 Offshore GW	RES 4-7 ind GW	Total GW
January	33353	18	0	21227	11240	0	936	0	13	-67	14	1	7	0	22
February	31517	34	0	20863	10195	0	518	0	41	-93	21	3	9	0	33
March	26483	71	0	21080	5207	0	56	0	86	69	12	8	4	0	24
April	18838	100	0	16727	1872	0	79	0	205	60	14	12	7	0	33
May	3829	106	0	3985	185	0	0	0	322	-446	11	13	7	0	31
June	2661	95	0	2374	197	0	0	0	355	-5	9	9	6	0	25
July	2661	77	0	2415	180	0	0	0	357	-11	13	8	7	0	28
August	2661	84	0	2379	189	0	0	0	359	9	10	8	7	0	25
September	2661	78	0	2433	146	0	0	0	355	3	11	8	7	0	26
October	2661	54	0	2552	54	0	0	0	356	0	15	5	8	0	28
November	19496	27	0	16470	2531	0	0	0	242	467	12	2	8	0	22
December	31352	12	0	20469	10628	0	286	0	65	-43	31	1	12	0	44
Average	14800	63	0	11045	3541	0	156	0	230	-6	14	6	8	0	28
Maximum	51659	434	0	21303	18000	0	11550	0	429	14574	91	86	20	0	127
Minimum	2661	0	0	0	0	0	0	0	0	-16579	0	0	0	0	1
Total for the whole year TWh/year	130.00	0.55	0.00	97.02	31.11	0.00	1.37	0.00		-0.05	126	56	66	0	249

Own use of heat from industrial CHP: 0.00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		47790
Uranium =	0	
Coal =	4621	
FuelOil =	924	
Gasoil/Diesel=	18073	
Petrol/JP =	13296	
Gas handling =	2205	
Biomass =	8671	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		29324
Marginal operation costs =		1321
Total Electricity exchange =		2084
Import =	144	
Export =	-72	
Bottleneck =	2	
Fixed imp/ex=	2009	
Total CO2 emission costs =		15627
Total variable costs =		96147
Fixed operation costs =		129811
Annual Investment costs =		184970
TOTAL ANNUAL COSTS =		410928

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	1101	33496	79066	5258	0	16902	135824	0	0	0	0	0	12899	122925	122925	0
February	609	32922	64049	4644	0	16902	119126	0	0	0	0	0	0	119126	119126	0
March	66	33265	62514	3169	0	16902	115917	0	0	0	0	0	-121	116038	116038	0
April	93	26396	46129	2045	0	16902	91565	0	0	0	0	0	-2495	94060	94060	0
May	0	6288	47890	325	0	16902	71405	0	0	0	0	0	-19509	90914	90914	0
June	0	3746	47360	167	0	16902	68176	0	0	0	0	0	-13522	81697	81697	0
July	0	3811	49861	178	0	16902	70753	0	0	0	0	0	125	70628	70628	0
August	0	3754	48354	207	0	16902	69218	0	0	0	0	0	423	68795	68795	0
September	0	3839	55408	245	0	16902	76394	0	0	0	0	0	534	75860	75860	0
October	0	4028	49338	284	0	16902	70552	0	0	0	0	0	-1030	71583	71583	0
November	0	25990	58402	2823	0	16902	104118	0	0	0	0	0	14591	89527	89527	0
December	337	32300	44310	5143	0	16902	98992	0	0	0	0	0	8077	90914	90914	0
Average	183	17429	54365	2034	0	16902	90914	0	0	0	0	0	0	90914	90914	0
Maximum	13588	33617	116495	9934	0	16902	173459	0	0	0	0	0	80799	173459	173459	0
Minimum	0	0	0	0	0	16902	20747	0	0	0	0	0	-70167	20852	20852	0
Total for the whole year TWh/year	1.61	153.10	477.55	17.87	0.00	148.47	798.59	0.00	0.00	0.00	0.00	0.00	0.00	798.59	798.59	0.00

RES Share: 25.5 Percent of Primary Energy 60.2 Percent of Electricity 340.2 TWh electricity from RES 01-June-2018 [14:41]

Appendix

Interview with Philip Litz, Agora Energiewende

What is yours general view on how Germany's energy system could like by 2030? And then can you talk about different energy sectors such as transport, heat and electricity?

First off all, the description will be given how we defined the energy system by 2030. We include sustainability, climate, policy, cost-efficient and security of supply targets. We specified them as clear as possible and then take a look at different scenarios which are already existent from environmental, economical ministries, different organizations, and then took a deep look to see what they have in common. All of the models are cost-efficient, marginal cost based energy models. More or less these energy models come with similar conclusions by 2030. The main take away message is that by 2030 there are 3 main strategies. The first one is in order to reduce GHG emissions by 55% the coal and lignite production has to be cut by half, while natural by 20%. The second strategy is to reduce the energy efficiency by 30%. And the last aim is to double the renewable share to 30% in total energy mix.

Now let's break it down to different sectors, and first start with the electricity sector. Even though the production of coal power plants will reduce, they still suppose to be be in the system by 2030. Renewable share should double to 60% in the electricity share. However, this number can be even higher because new government set to increase this share to 65%. Off course at that time nuclear power will be phased out. Even though the electricity will be used more efficiently, but due to sector coupling and the demand from electrified heat and transport sectors, the power demand should remain stable.

In the heat sector will be seen significant energy reduction. Currently the heat sector is dominated heated mainly by natural gas, but in the future the share will be slowly taken by renewable sources, which should supply one-third of heating needs by 2030. Also the heating sector will be electrified, and it expected to have 5-6 millions of heating pumps.

Before starting to describe transport sector, it needs to be said that different sectors such as heat, electricity and transport have their own targets which by being accomplished meets the overall countries goals.

Currently the transport sector in Germany is mainly running on fossil fuel, and it is the only sector with the increasing emissions. The targets by 2030 are to reduce the oil consumption by 40% and the efficiency by 30%. Conventional cars with 35-40% efficiency lose a significant amount of energy. Therefore, by 2030 these cars should be changed with more efficient cars, such as electrical cars.

Now I would like to ask the following questions for every sector. Can you say if it is possible to reach 10-12 million electrical cars by 2030?

Yes it can be done. Looking to the growth rates in California, China, Norway it is definitely possible, and it is not a technical question but more political one. Also considering the production car capacities in Germany with the right strategies it can be done, even though its ambitious target.

At this moment electrical cars are not competitive with cars which are running on fossil fuel. If there are any estimates, when electrical cars could become competitive in the future?

It basically depends on the batteries cost, how fast the prices will fall down. However, the Bloomberg Energy Finances predict that electrical cars will reach market equilibrium by 2025, while other organization forecasts this to happen few years later. Even though the electrical cars will become competitive by 2025 they still will need additional policies, or taxes on the other side, such as CO2 tax for example.

Moving back to the heating sector, it seems that a lot of effort will be made to electrify the sector. High number of heat pumps will have to be introduced. The question would be if HP is competitive at the moment, and if not do they need incentives?

First of all they need incentives. When the energy models are made for the future, the results shows that the cheapest option for home needs are HP. However, to reach these numbers there are some obstacles. People who used to install heating systems in the homes are used to install gas-fired boilers, and now to change the technology some time is needed for this transition. And also new set up programs needs to be designed.

Compared with Denmark, the DH share in Germany is rather low, and it doesn't seem that DH will be expanded in the future. Can you give reasons for this?

First point is that Germany has many countryside areas where to introduce DH systems doesn't make sense economically. For example, Bavaria region has 8 million people and only 1 million are living in the city. The second point is that historically the heating in Germany was based on coal in individual boilers. So differently than in Denmark, new DH needs to be build. However, where houses are old or have high energy needs to install new grid systems can be economically feasible.

How the Germany is preparing to deal with the increasing number of variable renewable energy sources in the future? What steps needs to be taken to smoother this transition looking from system operator's point of view?

There are few things to consider. First is if 60-65% of renewable to cover electricity needs will be placed in the system, coal power plants, at least half of them needs to be phased out. If this not happen, than Germany will be forced to export electricity in significant amounts. The other thing is grid infrastructure. Three new lines from North to South needs to be build in order to move wind production to south, and vice versus when it comes to the solar PV production. However, overall it shouldn't be a problem. Indeed, we didn't have even one day when all electricity demand was covered only by renewable energy sources.

Most experts agree that coal power plant needs to be reduced, but is it realistic to do that by 2030?

In order to meet climate goals the coal capacity needs to be phased out by half. But when it happens and how much of coal power plants will be shut down at this moment is not clear as the government currently discuss this issue. This question depends on political will. And if the government gives the signal for the market by introducing the instruments such as higher carbon tax, then naturally the capacity of power plants will decline.

However, from energy economics points of view there is not a problem to have coal power plants in the system by 2030. They production can be combined with renewable energy and if the surplus productions are in the system the good connections to neighboring countries lets to export this excess electricity production.

How is realistic to meet climate goals by 2020 and 2030?

First it needs to be distinguished, is it realistic politically and then technically. The target for 2020 is -40%. It is basically unreachable target. Most of the coal power plants will have to be shutdown. And it is too fast to do that by companies, system operator.

In coal industry around 30000 people currently are employed, and if it happens in one day all these people will lose their jobs. However, in a period of 10-15 years is possible to solve this problem.

The logic step would be removed the overcapacity of coal power plants which is 5-7 GW, and then the rest will be removed the next decade. Even the coal power plants will be phased out totally, they are responsible only for one third of the total emissions, where heat and transport sectors can be blamed for the rest. These sectors can be a big problem for Germany when it comes to reach climate goals in the future.

Do Germany's energy system needs additional storage technologies for variable renewable energy integration by 2030?

I will talk about long-term storage, not short-term storage such as batteries for example, which are used for primary or secondary reserve markets. I don't see them as an option, together electrical cars which can give back electricity to the grid, for long-term storage.

One of the key questions for what we need this additional storage? We have only around 1000 hours per year for over exceeding capacity. Plus when we taking into the consideration interconnection capacity which is around 50% higher compared with other countries, and then the overcapacity of power plants, where natural gas capacity alone consist of 30 GW. So basically the question if additional storage is needed, it depends of the flexibility options, which option can be the cheapest.

There is definitely no potential for pumped hydro power, and mainly because Germany has so much flexibility in the system. Therefore, they are not used so often. I don't see if there will be specific projects for storage technologies by 2030. But where I see potential is for big cities which have extended DH system and wind power. Therefore, cities like Berlin, Bremen, Hamburg are planning to go for heat to power.

The second option is power to gas or power to liquid. However, what it can be seen from the models is more expensive compared with direct use of electricity. They can become competitive after 2030.

Do you see a potential for batteries combined with solar PV for home needs?

The batteries become cheaper and solar PV become cheaper. Plus the levies or taces system is designed that it's cheaper for customers to get the electricity from own system than from the grid. Therefore, to make solar PV+batteries more competitive, other fuels needs with additional taxes become expensive. Overall message would be that off course there would be houses which would install solar PV and batteries, but it's more of contributing to the energy transition than making significant profit from this investment.

It's a broad question, but maybe you can compare two different approaches of integrating surplus electricity production from RES. One way would be is to extend interconnectors capacity lines, while the other is to integrate electricity domestically into different sectors such as heat and transport. Can you say what are the benefits and drawbacks of these approaches?

Exporting electricity abroad its not only the cheap option, but also it gives high security of supply. So when you combine these two benefits its becomes a better option compared of electricity integration regionally in heat and transport sectors. So you have double plus. In Germany new capacity lines are built to extend the grid. There is a target for grid operators which are 50% interconnector's capacity of the overall future maximum load. Thus it results that in the future Germany will have around 25

GW of interconnectors capacity. Now the capacity is around 17-18 GW. From our organization perspective is really clever way to deal with overproduction of electricity, because you can integrate RES and reduce the conventional power plants capacity.

Some countries will profit from cheap electricity, others not so much. Germany now is a net exporter, exporting 50 TWh of electricity annually to neighboring countries. Its 10% of annual electricity production.

Can Germany profit from exporting high amounts of cheap electricity to neighboring countries?

It's the question who in Germany will lose or profit. The main driver its not interconnectors, but more policies. For example, if coal power plants will not be phased out that they can produce electricity and export the surplus. For consumers it's a win-win situation, with less capacity, consumers can get the electricity really cheap, or benefit from negative wholesale prices.

Interview with Heinz-Uwe Lewe, Policy Officer

What is yours general view on how Germany's energy system could like by 2030? And then can you talk about different energy sectors such as transport, heat and electricity?

I will start with electricity sector. We have around 35% renewable sources in electricity sector. The expansion of renewable sources in the past was based on EEG policy; it is basically a feed-in-tariff. Every consumer pays the price for this and the producer for every kWh produced earns additional money. Now this system was changed with auction system. Now the government controls the speed of how much renewable sources will be in the future. Some people argue that the auctions with the maximum capacity to win will not help to archive 2030 RES targets. But theoretically, the governments can count how much capacity can be given for auctions, and thus it can be controlled. In the past feed-in-tariff system ensures long-term security for the investors, now investors by bidding the lowest price to win the auction cannot be so secured. However, from economic point of view this auction system can lower the price for the whole system.

So in general to meet the 2030 targets, you need to expand the renewable share and the grid. The new lines from North to South needs to be build to transport wind power down and solar PV up. Also low and medium voltage lines need to be expanded.

Heating sector

The biggest renewable source for heating is biomass, and gradually HP takes the bigger share in this market. We as the government body give a a public support for people who invest in this technology. With the incentives HP almost become competitive with gas-fired boilers. However, the expansion of HP will not be about incentives but it will be about new building regulations. Basically for new houses it will be impossible to install a gas fired boiler because you will never achieve the standard. On the other hand the gas is super cheap.

Another problem in the heating sector is experience related with HP installation. Plumbers used to install gas-fired boilers for 10-15 years, and have a good knowledge about these systems.

The Germany wants to increase the efficiency of the houses. However the goal usually is set to high, 2% of houses per year should be renovated but in reality this number usually is lower. There is not enough workers.

DH has share of around 10%. In northern Germany we have cities with DH systems which are supplied by CHP plats fed on coal, waste heat and little biomass. The problem is that for new buildings its not economical to install the grid because there is not enough demand. It works for cities with old buildings. In cities with already established DH grids, coal or natural gas can be changed with renewable energy sources. In the future DH share should remain the same.

In the future for DH system deep geothermal as the sources can be used, or large scale HP. Solar thermal capacity will not be significant as well. Biomass could be used for industrial process, where high temperatures are needed.

In Denmark, almost all CHP plants are building together with thermal storage. In Germany is not the case at all. The problem with CHP and DH is that most of them are based on fossil fuel. So if you want to phase out them from the electricity sector, they are still connected to DH grid. Therefore you have dependencies.

Transport sector

Transport sector has 5% of renewable, and the last 20 years basically didn't do basically anything to increase this number. The CO2 emissions in this sector are increasing.

Can you say if it is possible to reach 10-12 million electrical cars by 2030?

It will be hard to reach this target. For this number you need a lot of charging stations and significant grid expansion. There is discussion which direction should go future transport, be electrified or be based on synthetic gas. Some people say that the future transport will be still based on combustion engines, only with renewable gas such as hydrogen for example. In the desert, electricity from solar PV can be produced in the future as 1 euro cent per kWh. Therefore synthetic fuel then could be exported to Germany. On the other hands the price of batteries also can go really down. But even if it the case, still you have to pay grid fees. Its open question, and probably will be mix of different fuels. Its hard to predict how fast the technologies will be developed.

How the Germany is preparing to deal with the increasing number of variable renewable energy sources in the future? What steps needs to be taken to smoother this transition looking from system operator's point of view?

There are definitely needed some efforts to smoothen this transition. Grid expansion is really important. The grid expansion is delayed due to public acceptance. Politicians have to explain that more and more renewable will be installed, and the landscape will be changed. Smart grid also will play a big role. Its important, and if possible, to balance the system on low level.

Do Germany's energy system needs additional storage technologies for variable renewable energy integration by 2030?

In the last couple of years, it was seen that for short-term battery storage between1-5 MW, could be competitive in the balancing market. And people until the supply exceeded demand could make some money.

Potential for hydro pumped power is limited because of the public acceptance. On the other hand they don’t make a lot of money because the market its not in favor for this technology.

Batteries with storage for home needs are quite popular at this time. People can supply 60-70% of their needs with this combination of technologies, which is much cheaper than the electricity from the grid. However, even though if lets say 99% of home demand will be cover by batteries and solar PV, you still need to maintain the grid, and this one percent can be really expensive. Now this system work for people, and they can make money out of it, however in the long-term someone will have to pay for the grid.

How is realistic to meet climate goals by 2020 and 2030? And why coal power plants still competitive? Is it realistic to phased out coal power plants completely.

In the last couple of years the CO2 emissions are constant. Its most likely that the 2020 climate target will not be archived. Now the new commission has to come up with the plan when to phased out coal power plant completely. My guess it could happen by 2035-2045. Before 2035 it will not be realistic. There are few studies which claimed that the most cost-efficient way to reduce CO2 emissions it to change coal with natural gas. However, after the nuclear phase-out the share will take coal power plants which increase the CO2 emissions.

Now why coal are so competitive. A lot of coal power plants are 30 years old, and the capital costs are already paid. Coal are imported from Australia, South Africa at the cheap price and the carbon tax is rather low. One study in Germany concludes that in order for natural gas to outcompete coal the carbon tax should be around 20-30 euros at least. The coal competitiveness is basically determined by variable costs, which is fuel, and when the price is low, the price to produce the electricity is rather low as well.

Coal is responsible only for one-third of CO2 emissions. What about heat and transport sectors? It seems that the biggest focus is for electricity sector.

Most emphasizes is for electricity sector. But when it comes sector coupling it make sense to do that, because the electricity can be used for HP and batteries in electrical cars can charge the grid.

It’s a broad question, but maybe you can compare two different approaches of integrating surplus electricity production from RES. One way would be is to extend interconnectors capacity lines, while the other is to integrate electricity domestically into different sectors such as heat and transport. Can you say what are the benefits and drawbacks of these approaches?

The drawbacks of interconnectors approach that when Germany has surplus of lets say wind production, countries like Denmark have similar situation. Therefore, when there is no big demand the electricity is exported at the cheap price. Interconnector lines expansion can be beneficial when your neighbors have different energy systems, such as Norway for example.

The way it can be compared, it could be a calculation and the price comparison between the price of interconnector’s capacity and the price of integrating electricity domestically.