MSc Program
Environmental Technology & International Affairs

EU-Policies on Transmission Network Development: In regard to the European Union's Energy Targets

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Dipl. Ing. Dr. Klaus Rapp

Justina Rauch

00918332

Vienna, 04.06.2018

Affidavit

I, **JUSTINA RAUCH,** hereby declare

1. That I am the sole author of the present Master's Theses," EU-POLICIES ON TRANSMISSION NETWORK DEVELOPMENT: IN REGARD TO THE EUROPEAN UNION'S ENERGY TARGETS", 65 pages, bound, that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. That I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad

Vienna, 04.06.2018

Signature

Abstract

The European Union has set energy targets to reduce CO_2 emissions. Until 2030 the power sector is supposed to cut 54 to 68 % of its Green House Gases. In order to achieve this goal power generation needs to change significantly. This thesis demonstrates that enormous Transmission Network Development is essential for integrating large shares of variable renewable energy sources. In order to do so four future 2030 scenarios from different stakeholders, Greenpeace, McKinsey, ENTSO-e and the Climate Change foundation are analysed in regard to the electricity production and necessary transmission network capacity. In a follow up step European Union policies are assessed in regard to the objective of guaranteeing sufficient transmission lines and capacity for a low carbon energy sector. EU Regulation (EC) No 714/2009 on access to cross-border electricity infrastructure and Regulation (EU) No 347/2013 on trans-European energy infrastructure is analysed in more detail and four major challenges for European grid development are identified: uncertainty in the energy sector, bottom up approach in European network development, permitting process and unbundling.

Table of Contents:

List of Abbreviations

AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
CCS	Carbon Capture and Storage
CEF	Connecting Europe Facility
CBCA	Cross-Border Cost Allocation
DC	Direct Current
ENTSO-e	European Network of Transmission System Operators for Electricity
ETSO	European Transmission System Operators
EU	European Union
GHG	Green House Gas
GTC	Grid Transfer Capacity
GVA	Giga Volt Ampere
MW	Megawatt
GW	Gigawatt
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
kV	Kilovolt
kWh	Kilowatt hour
MWh	Megawatt hour
NRA	National Regulatory Authority
NTC	Net Transfer Capacity
PCI	Projects of Common Interest
RES	Renewable Energy Sources
TEN-E	Trans-European Networks Energy
TEU	Treaty on the European Union
TFEU	Treaty on the Functioning of the European Union
TSO	Transmission System Operator
TTC	Total Transfer Capacity
TWh	Terawatt hour
TYNDP	Ten Year Network Development Plan

1. Introduction

Climate change is one of the greatest challenges the world is facing today. It is a global problem that has been predominantly caused by the industrialised world. Especially the burning of fossil fuels and extensive agriculture and farming have contributed to the steadily increasing Green House Gas (GHG) concentration in the atmosphere. The global effort to mitigate climate change is reflected in the *Paris Agreement* that entered into force in November 2016. Its goal is to limit warming to a "global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (UNFCCC 2015, Art: 2).

The European Union (EU) demonstrated its effort to reduce GHG emissions and to help to achieve the 2°C target, in its Communication on "A Roadmap for moving to a competitive low carbon economy in 2050." The objective is to reduce 80-95 % of GHG by 2050 in comparison to 1990 levels (COM (2011) 112 final 2011, 3). In order to achieve that intermediate targets have been set for 2020 and 2030. By 2020 a reduction of 20 % of GHG is aspired within the EU and by 2030 around 40 % (COM (2014) 15 final 2014, 5). Major savings are supposed to come from the energy sector, and more precisely from the power sector.

The electricity sector is supposed to reduce its GHG emissions between 54 to 68 % until 2030 and between 93 to 99 % until 2050 (COM (2011) 112 final 2011, 6). The European Commission outlined that the energy transition is likely to entail a couple of major structural changes. Namely, that there will be higher capital expenditure but lower operational costs, electricity will be increasingly important, electricity prices rise until 2030 and will decrease afterwards, the share of renewables rises, energy demand will need to decrease, Carbon Capture Storage (CCS) technology could be vital and nuclear energy will continue to play an important role in the energy mix (COM (2011) 885 final 2011, 5–8).

The economical and technical feasibility of an energy transition towards a carbon free electricity sector has been demonstrated by countless authors and studies (Roadmap 2050 2011; Ackermann et al. 2014) and is hence seen as granted, for the purpose of this paper. This thesis is having a closer look at the development of the power sector, to achieve these ambitious climate targets. More demand in electricity and increasing employment of intermittent renewable energy resources (RES) has a significant influence on the electricity transmission network.

How the European grid needs to develop, to be in line with an energy transition until 2030, in order to pursue the climate change targets until 2050 is the main concern of this paper. Furthermore, a closer look is laid on the EU policies that are concerned with the development of the electricity market, and infrastructure. The objective is, to evaluate measures taken on a Union level and to identify challenges in network development. For the purpose of this thesis, the emphasis is laid on transmission network development. However, it is necessary to mention that without doubt, also distribution networks as well as smart grid play a vital role in the energy transition.

Four research questions are reflected in the structure of the main part of this thesis. The second chapter is focusing on the connection between the energy transition and the raising demand in transmission capacity. It starts off with an introduction of the transmission grid and its functions, and concludes with four reasons that explain the urgent need for network development in regard to the decarbonisation of the energy sector.

The third chapter is devoted to the question, of how the transmission network needs to look like in 2030, if the European Unions energy targets are fulfilled. To approach this issue four studies from different stakeholders are analysed and compared. It will be shown that they all confirm the need for major grid development, but that they differ greatly, if it comes down to clear numbers, data input and description thereof. Hence, it is difficult to draw one ideal European transmission network for 2030, as there are too many variables concerning electricity generation, consumption as well as major flow patterns.

The following part is focusing on EU-policies and their potential in addressing the issue of necessary grid development, to achieve the GHG emission reduction target in the power sector. Two major pieces of legislation that are the most significant ones for this question will be analysed in more detail. The Regulation (EC) No 714/2009 on "conditions for access to the network for cross-border exchanges in electricity" and Regulation (EU) No 347/2013 "on guidelines for trans-European energy infrastructure" are setting the basis for EU wide network planning. The effectiveness of these measures is assessed against the data available on transmission network projects from the European Network of Transmission System Operators for Electricity (ENTSO-e) and from the Agency for the Cooperation of Energy Regulators (ACER).

The final chapter is aiming to outline major difficulties and challenges for providing enough transmission capacity and sufficient network development. In order to do so, four dilemmas have been identified that pose challenges to achieve this. These dilemmas are the outcomes from comparing the ideal scenarios in chapter 3 with the possible impact and efficiency of the measures taken on a Union level, analysed in chapter 4.

The importance of this work lies in the demonstration of the necessity and the dimension of investment in electricity transmission infrastructure, in order to reduce GHG concentration in the atmosphere and, moreover, to draw attention to the weaknesses of the contemporary policy system.

2. Transmission Network

2.1. History

A secure and reliable electricity supply in Europe is nowadays a matter of course for many. A large transmission network is responsible to transport the electricity from the point of generation to end consumers. The Austrian electricity grid alone, expands over 258.907 km and would be able, if lined up, to span more than six times around the globe. Most of the lines are part of the distribution network with a voltage of 1 kV and lower, or in the medium voltage range up to 110 kV. The last three per cent are high voltage transmission lines in the range of 220 to 380 kV, necessary to transport electricity over long distances without high losses (Österreichs Energie n.d.).

In the late 19th century, technical discoveries made it possible to generate electricity for human consumption. Decentralised power generation with a local transmission line was the way to deliver electricity to machines and light bulbs. Only in the 20^{th} century, large grid networks made centralised electricity generation and wider electricity distribution to households and industry possible (Würfel 2017, 2). There had been a considerable progress, throughout the twentieth century, that made it possible to create an interconnected European Transmission Network, evolving from many small independent local electricity grids (Horstmann 2006, 100).

The first steps, from national transmission systems towards a European cooperation, were taken in the 1950's with the foundation of the Union for the Coordination of Production and Transmission of Electricity (UCPTE). It was a voluntary coordination between the eight founding members, among them Austria, France, Western Germany, Italy and other countries in middle and Western Europe. The aim of the Union was to use generated power as efficiently as possible, and to be able to exchange their electricity surpluses, especially in the light of the post World War II period, where energy was a scarce good. Since then, a continues extension of grid connections advanced in Europe (Horstmann 2006, 102–3).

Further significant changes in the European energy market, and hence, also for the transmission grid occurred in the early 1990's. In the Treaty of Maastricht 1992, the European Union received the competence to take "measures in the sphere of energy […]" (Boisseleau and Roggenkamp 2005, 1). The first European Energy Package was adopted four years later and was integrated into national law in 1998. The EU and its member states envisaged a common European electricity market that would allow consumers to benefit from free market competition.

Before the liberalisation of the electricity market, generation and production was public administered, and often regionally restricted. Consumers had hence no option to choose between different electricity producers. With the first Energy package the EU paved the way towards an integrated and liberalised electricity market. (Würfel 2017, 6–7). With the start of the opening of the electricity market, the electricity generators dropped out of the UCPTE and re-joined together under the umbrella organisation of the European Transmission System Operators (ETSO) in 1999 (Horstmann 2006, 105).

The Second European Energy Package followed in 2003 and aimed at further harmonization in the energy sector, a necessary measure to facilitate increasing cross-border exchange among member states (Boisseleau and Roggenkamp 2005, 2). The last important package of EU legislation regarding energy politics was adopted in 2009 and issued final important measurements to disperse the vertical structure of the electricity market. Effective unbundling, the juridical separation between electricity producers and transmission system operators (TSO) was necessary to guarantee non-discriminatory access to the network, a prerequisite for a competitive market (Directive 2009/72/EC, (9)-(11)).

Until 2013 the cross-border trade in electricity roughly tripled compared to the early 1990's (Bahar and Sauvage 2013, 29). The European Network of Transmission System Operators for electricity (ENTSO-e) was established in 2009, with the third energy package, as the successor of ETSO. With an increasing electricity exchange among member states, more cooperation is needed. Hence, ENTSO-e's main responsibilities are to establish common rules of procedure, and to stipulate grid development. For a growing and increasingly interconnected electricity market, the European transmission network needs to be adopted appropriately. One of many tasks of ENTSO-e is, to assess the transmission network, and to recommend, in cooperation with the Agency for the Cooperation of Energy Regulators, necessary grid development and infrastructure projects.

The transmission network is the integral linkage between electricity production and consumption and is hence subject to change, if power generation or consumer behaviour alters, in order to provide constant energy security. The transition towards a carbon free energy sector, therefore, poses new demands on a European electricity grid. These challenges will be discussed in more detail in the following chapters.

2.2. The European Energy Transition

2.2.1. Setting the Scene for GHG Reduction

The energy transition is the European approach to climate change mitigation. Decreasing CO_2 emissions in the energy sector means primarily, increasing the use of electricity from Renewable Energy Resources (RES), like wind and solar energy. The European Union has set legally binding greenhouse gas emission reduction targets for 2020, entailing the goal of 20 % energy from RES as a total in the European Union (Directive 2009/28/EC, Art: 3).

The European Commission envisions a complete energy transition in its "Roadmap for a Decarbonised Economy by 2050". The roadmap entails the plan to move towards a nearly complete electricity consumption from RES, resulting in a CO_2 decrease of up to 99 % in power generation (COM (2011) 112 final 2011, 4). In order to achieve the ambitious green house gas (GHG) reduction targets until the middle of the century, the intermediate goal for 2030 is a decrease of CO_2 equivalent between 54 % and 68 % in the power sector compared to 1990 (COM (2011) 112 final 2011, 6). The GHG reduction shall be achieved with the use of low carbon technologies for electricity generation. In 2030, 75 % to 80 % of the electricity configuration shall either be from RES, nuclear energy, carbon capture and storage technologies or other low carbon technologies (COM (2011) 112 final 2011, 6). However, unlike the 2020 European energy targets, the roadmap for 2050 is not legally binding, but rather a proposal of the Commission, of how to proceed in the next decades in the light of global warming.

An energy transition connotes to more than a mere upgrading of electricity generation capacity, most prominently the installation of windmills and photovoltaic. As the potential for further deployment of hydropower is limited, major emphasis is laid on solar and wind energy (Brauner 2013, 87). These energy sources, however, have the great disadvantage that they are very volatile in the sense that electricity generation is fluctuating and cannot be influenced. It is not demand, but meteorological conditions that are decisive for the electricity generation.

Therefore, the larger the amount of RES in the electricity sector, apart from hydropower, geothermal energy or biomass, the greater is the variability of energy generation. For this reason, the deployment of RES is only one factor in the energy transition. There are four other developments that come along with increasing RES and pose necessary preconditions for achieving a significant decarbonisation:

First of all, energy efficiency is of great importance. Since the industrial revolution there had been a steadily increasing demand for energy. Without controlling and reducing energy consumption, now and in the future, society will sooner or later reach the "point of no return." It describes the situation at which the whole potential of renewable energy is used up without satisfying the overall demand (Brauner 2016, 13). At that point, energy consumption has passed a certain threshold at which only further use of fossil fuels can help to meet demand. This would be a fatal situation within the European energy transition, as reducing energy demand is more much more difficult than decelerating in the first place. This is why the European Commission emphasises to increase energy efficiency by 20 % compared to the energy demand prognosis for 2020 and beyond (European Commission 2018b).

Second, in order to enable secure and reliable electricity, additional measurements need to be taken. There is a need for flexible power plants with short start up and close down phases to complement variable electricity generation from RES. If the wind is not blowing and the sun is not shining, flexible power plants need to fill the gap within a very short period of time. Investments into gas fuelled power plants that have the ability to operate full load within a couple of minutes is therefore important (Panos 2013, 147). However, the electricity market leaves few incentives for investors at the moment (Kästner and Kießling 2016, 20–21).

A third measurement that can contribute to balance the volatility and peak loads of RES would be energy storage facilities. Electricity cannot be stored, but has to be consumed in the moment of generation. Hydropower pump and storage plants and batteries, however, can help to accumulate energy. The use of Hydropower storage plants is the easiest and most efficient way to store energy, but areas, where they can be potentially built are limited. Lithium-ion batteries represent a perfect storage medium, however, up until now large-scale use is not economically (Würfel 2017, 103–5). Further research in storage capacities and development of what is feasible at the moment is crucial for further installation of intermittent RES.

The last, and probably most important development in regard to the rising use of RES is transmission network development. High penetration of variable RES poses enormous challenges on TSOs. It is their duty to balance voltage and frequency to guarantee secure electricity supply. Electricity exchange between countries or bidding zones can help to balance flows in the transmission system. Moreover, areas with high wind and solar energy potential are often far away from consumer centres. Hence, sufficient grid capacity must be available to transport electricity from point of generation to consumption.

The last point mentioned, is the focus of interest in the next pages, where the link, between the increasing need in transmission network infrastructure and higher penetration of electricity from RES, will be elaborated.

2.2.2. Variable RES and Transmission Network Development

Europe’s pioneer in regard to the energy transition is Germany. The country aims to move from nuclear energy and fossil fuels towards extensive deployment of renewable energy. Since 2007 until 2016, Germany more than tripled its installed renewable energy generation capacity from 31.000 MW up to nearly 100.000 MW. Fluctuating RES, namely solar and on shore wind energy constitute the largest share in Germany's renewable energy mix (Bundesnetzagentur 2018b). In 2016 electricity from RES made up almost half of the total installed capacity of 212.000 MW (Bundesnetzagentur 2017, 7).

However, significant amount or renewable electricity generation is void, if it cannot find its way to the consumers. In 2016, German TSOs were forced to curtail 3743 GWh. A number much higher compared to the years preceding 2015 where less electricity from variable RES was generated, as can be seen in figure 1. Curtailment in 2016, however, was surprisingly smaller than the previous year. This can be explained with the low amount of wind energy generated, that year.

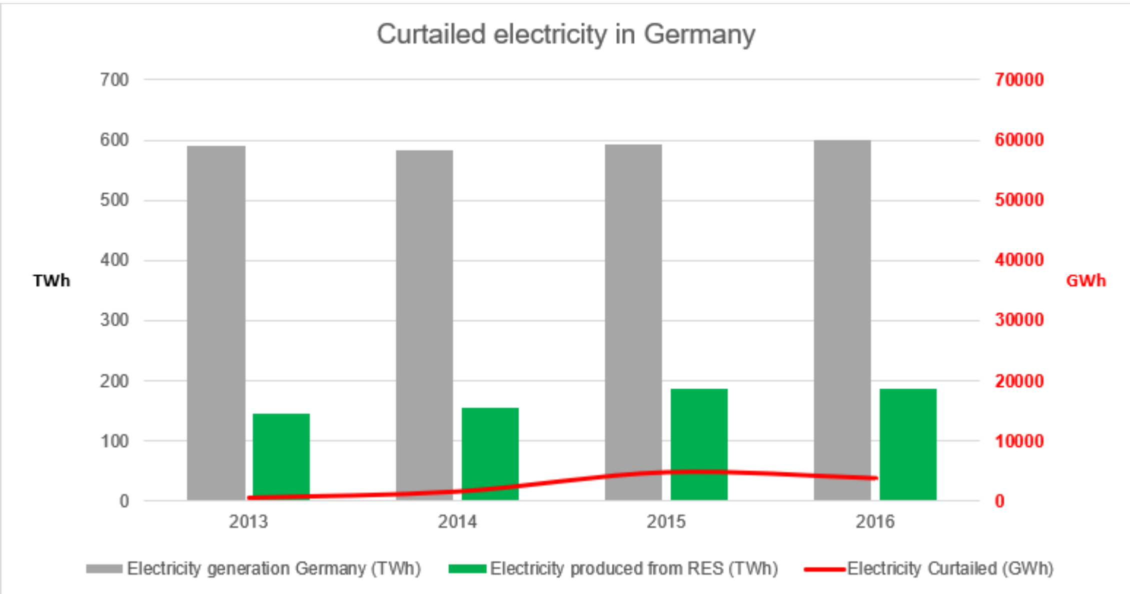

Figure 1.: Increasing Penetration of RES leads to increasing Curtailment.
Sources: Bundesnetzagentur 2014, 2015, 2016, 2017.

Between 2014 and 2015 the share of electricity produced from RES in comparison to overall generation increased by around 5 % within one year. The electricity, within the same timeframe, that could not be consumed, and was curtailed by TSOs tripled, from

1581 GWh in 2014 to 4722 GWh in 2015 and in 2013 electricity curtailed in Germany accounted to only 555 GWh. The amount of electricity that needed to be redispatched even accounted to 16.000 GWh in 2015. Balancing costs for redispatching and curtailment added up to 890 million euro that year (Bundesnetzagentur 2016, 8).

Balancing costs are rising with increasing deployment of variable electricity from RES in Germany. One of the main reasons is insufficient transmission grid development. Grid capacity bottlenecks demand curtailment or redispatchment of electricity flows in order to keep the network secure and stable. More than 87 % of the electricity that had to be curtailed was wind energy. More investments in grid infrastructure would contribute to prevent congestion (Bundesnetzagentur 2016, 101).

There are four main reasons why there is an increasing demand in transmission network infrastructure if the European energy sector is decarbonising:

First of all, it is that the distance between electricity production and generation is strongly tending to increase, especially as RES potentials are mainly situated at the outer skirts of the continent. Wind potential is prevailing in coastal areas and solar penetration is higher in the Southern countries. Consumer centres, however, remain in the cities. Consequentially, larger transport distances require larger transmission networks (ENTSO-e 2014a, 58).

Second, there is a need for long-range transport and trade of electricity from variable RES to even out electricity surplus from energy peaks. It is not only Germany, but also the European Union as a whole that experienced an enormous increase in capacity installations from RES. In 2014 almost a third of Europe’s electricity was generated from RES. In 1990 it were only 13 per cent (European Environment Agency 2017).

The EU has the great potential to profit from the common European transmission network and the internal energy market. It enables a more efficient use of electricity in trading it across borders. This can assist in balancing peak loads of wind and sun energy (Bahar and Sauvage 2013, 13). Areas with high demand are able to benefit from electricity overloads of RES in other regions. However, that is only possible, if sufficient grid capacity is available to transport large amounts of electricity across the continent. Especially, increasing cross-border trade can be useful to harvest the benefits of low carbon RES. However, more trade entails more transmission capacities between countries, an important development that did not keep up with increasing variable RES installations (Commission Expert Group on Electricity Interconnection Targets 2017, 25).

The third reason is that electricity from variable RES needs more installation and grid capacity for the same amount of electricity, compared to other energy sources. For instance, the Regional Group of Continental Central South[1] increased the installed capacity for electricity generation by 23 % from 420 GW in 2010 to 515 GW in 2016. Power plants running on fossil fuels decreased as a total share from 43 % to 36 % within 6 years and solar energy on the other hand increased from 4 % to 13 % (ENTSO-e 2017b, 17). At an almost constant electricity generation rate of 1562 TWh in 2010 and 2016, electricity production from RES only increased by 11 % in consideration of the significant increase of renewable energy generation capacity.

Highly intermittent energy sources like wind or solar have a small amount of full load hours per year. On average wind parks have around 1500 up to 4000 full load hours per year, where as off shore wind parks are usually on the higher end (Brauner 2016, 44–50). Compared to non-variable energy sources that possess an availability of 90 % or more, wind and solar energy need naturally much higher installation capacity, in order produce the same amount of electricity. This is demonstrated in figure 2 and 3 on the next page.

[1] The Regional Group Continental Central South is one of six regional groups classified

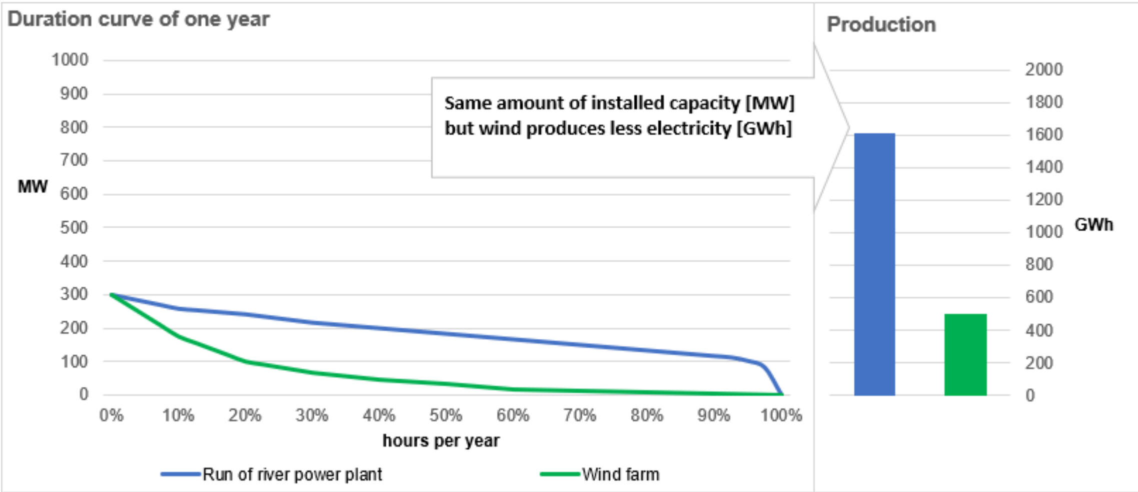

Figure 2.: Duration Curve Run of River Power Plant and Wind farm at the same installed capacity. Source: ENTSO-e 2017b, 19

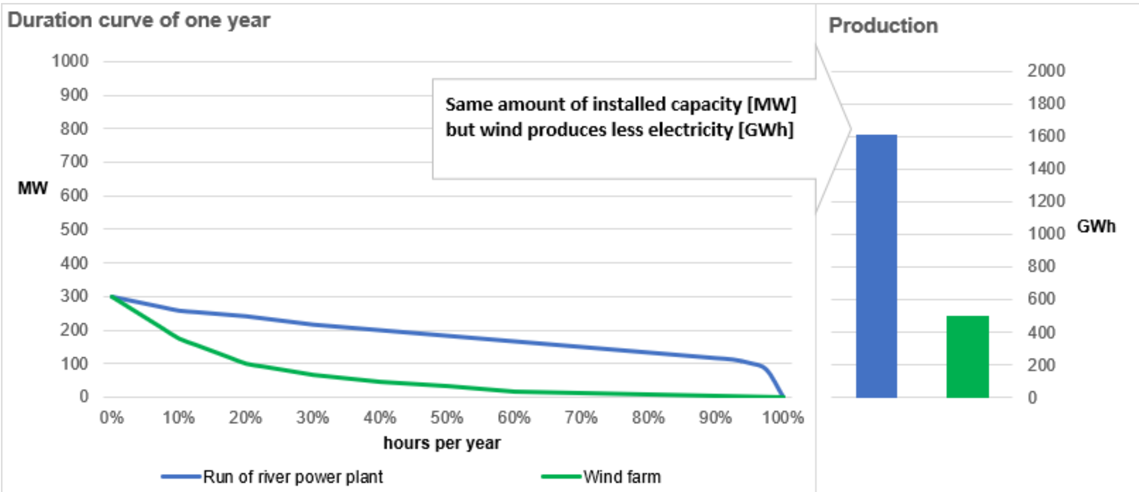

Figure 3.: Duration Curve Run of River Power Plant and Wind farm at the same installed capacity. Source: ENTSO-e 2017b, 19.

Hence, also the load from intermittent energy sources to the grid varies greatly. In order, to be able to transport the same amount of electricity from a wind park over a whole year, grid capacity needs to be much higher compared to, for example, a run of river power plant. The installed capacity of a run off river power plant is less than a third, compared to a windmill that is producing the same amount of electricity. At moments of wind peaks the grid, therefore, needs to have much higher capacity, compared to the rest of the year where wind is only producing moderate amounts of electricity (ENTSO-e 2017b, 19).

The last reason for the need of increasing transmission capacity is, that decarbonisation of energy means increasing use of electricity from RES. The European 2020 targets for the energy sector emphasize, not only on consumption of electricity from RES, but also, on consumption of RES for transport, and consumption of RES for heating or cooling (Directive 2009/28/EC, Art: 5). In order to diminish CO_2 emissions in the areas of transport and heating, even more electricity generation is necessary, for instance, for electric vehicles and heat pumps. With an overall GHG emission reduction of 80 % more electricity will be needed, even if there will be considerable efforts towards energy efficiency. Therefore, the more electricity generated, the more grid capacity is necessary.

The following graph shows historical electricity demand since 2000 and four different future estimates in 2030. The four different forecasts represent the assumptions of the energy scenarios that are discussed in the next chapter *Future Energy Scenarios 2030.*

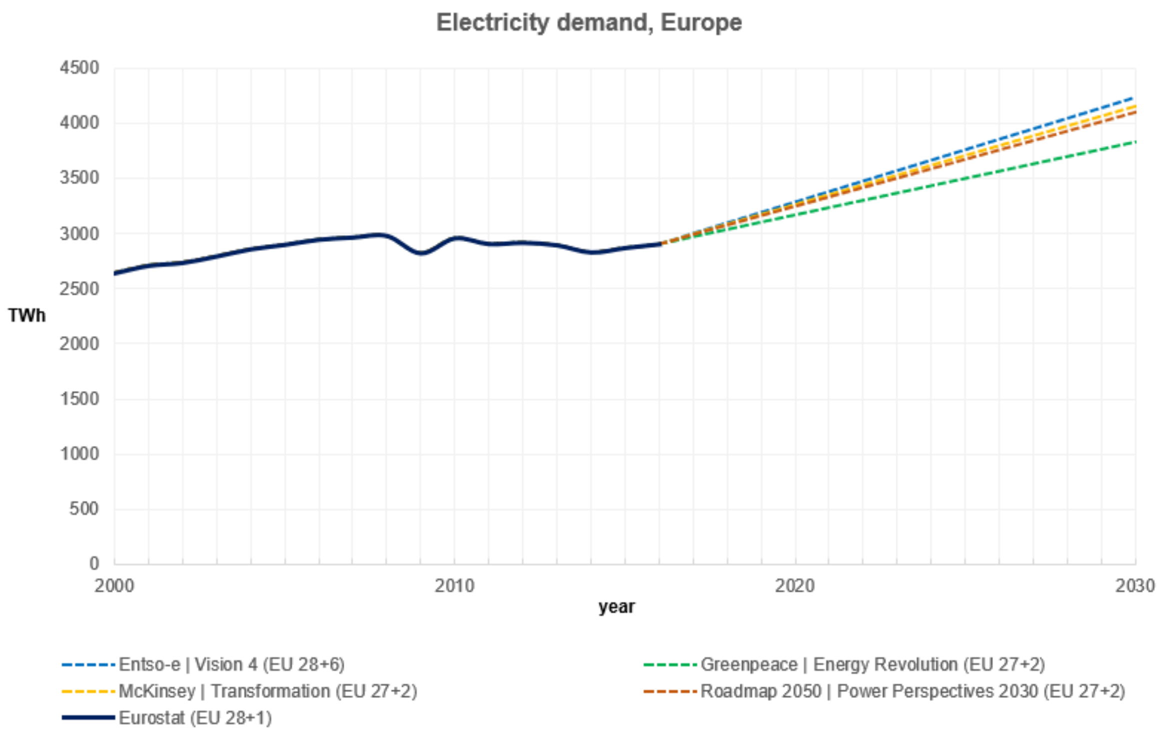

Figure 4.: Historical Electricity Demand in Europe and future prognosis of each Scenario. Source: Eurostat 2018.

During the last decade, the first step towards a European energy transition was taken, and considerable amount of new variable RES capacity generation has been installed. It was demonstrated that transmission network development is of great importance in order to achieve the decarbonisation of the energy sector. If there is insufficient grid adaption and electricity from wind or solar energy cannot be put on the grid and be transmitted to consumers, then increasing capacity generation of RES is costly, and not able to contribute to climate change mitigation to its full potential.

3. Future Energy Scenarios 2030

This chapter will analyse how a future grid, which aims at integrating large amounts of electricity from variable RES, will have to look like. In order to do so, different energy system scenarios are compared, all aiming to reach the EU 2030 or 2050 climate targets, namely the reduction of 80 % Green House Gases.

There is consensus that this encompasses an enormous change within the energy sector, however, how this change looks like exactly, is not as clear. The main potential in reducing CO_2 emissions lies within in the electricity sector. The amount of electricity that needs to be produced from renewable energy sources, in order to meet the target of 80 % reduction of GHG by 2050, and the interim target of 40% reduction by 2030, depends on many variables, like rising energy demand or energy efficiency. To eliminate GHG emissions within the energy sector, entails a shift towards rising electricity consumption. Different scenarios, therefore, assume different starting points.

The following chapters aim at analysing four different forecasts in regard to grid development from different stakeholders. All of them are drawing case scenarios that are in line with the European Union's 2030 target and are aiming to set necessary preconditions for pursuing the 2050 goals:

The environmental NGO Greenpeace commissioned the scenario "Powe[R]: A European Grid for ¾ Renewable Electricity by 2030." It is based on a publication, which relies on an energy model simulation pursued by Energynautics.

The consulting company McKinsey draws up the second scenario, the "Transformation of Europe's power system until 2050. Including specific considerations for Germany". It mainly tries to assess future outcomes in the light of the 2050 climate targets, rather than making proposals of how to best achieve them.

The third report "Power Perspectives 2030. On the Road to a Decarbonised power sector," was published by the Roadmap 2050 Project, which was initiated by the

Climate Change Foundation. It aims to outline the necessary conditions in 2030, in order to achieve 2050, and furthermore, to demonstrate that the envisioned energy transition is technically and economically feasible.

The last scenario that will be analysed and compared to the other reports, is the "European Green Revolution" vision. In the Ten Year Network Development Plan 2014 (TYNDP) ENTSO-e has developed four different visions for the year 2030. The vision that is the most economical one and the one being best on track with the low carbon economy 2050 will hence be used (ENTSO-e 2015b, chap: 4–5).

The energy transition entails significant changes in electricity generation and in transmission- as well as in the distribution networks. However, the scenarios that will be looked at in more detail in the next chapters focus on transmission networks, and not on necessary development in distribution networks.

3.1. Greenpeace's Energy Revolution Case

The Greenpeace 2014 Scenario is drawing up 3 different cases, however, only the Energy Revolution case is in line with the 2030 climate targets. The Greenpeace Energy Revolution case is very ambitious, as its goal is to demonstrate that a very high penetration of RES, together with a nuclear phase out and moderate grid extension is feasible.

It foresees that around 70 % of the electricity consumption is coming from RES in 2030, a necessary intermediate step to reach at least 95 % renewable electricity generation in 2050 (Ackermann et al. 2014, 7). In order to integrate the large amount of variable solar and wind energy, the Energy Revolution Case calculated that additional 26,275 km of transmission lines will be necessary. The scenario foresees additional 860 GW installation capacity of variable wind and solar energy in 2030 (Ackermann et al. 2014, 11). This is an enormous amount, considering that in 2013 total installed capacity in the EU was at around 958 GW (Eurostat 2017, Table 2).

Total installation capacity according to the Greenpeace scenario will be at 1484 GW, of which 1170 GW are from RES. Only one per cent of the installation capacity is covered by nuclear energy, and coal-fired power plants take up to 39 GW. By far the largest share of non-RES capacity, namely 230 GW is fuelled by gas (Ackermann et al. 2014, 29). The composition of the generation capacity is indirectly reflected in the electricity production shown in the graphic below.

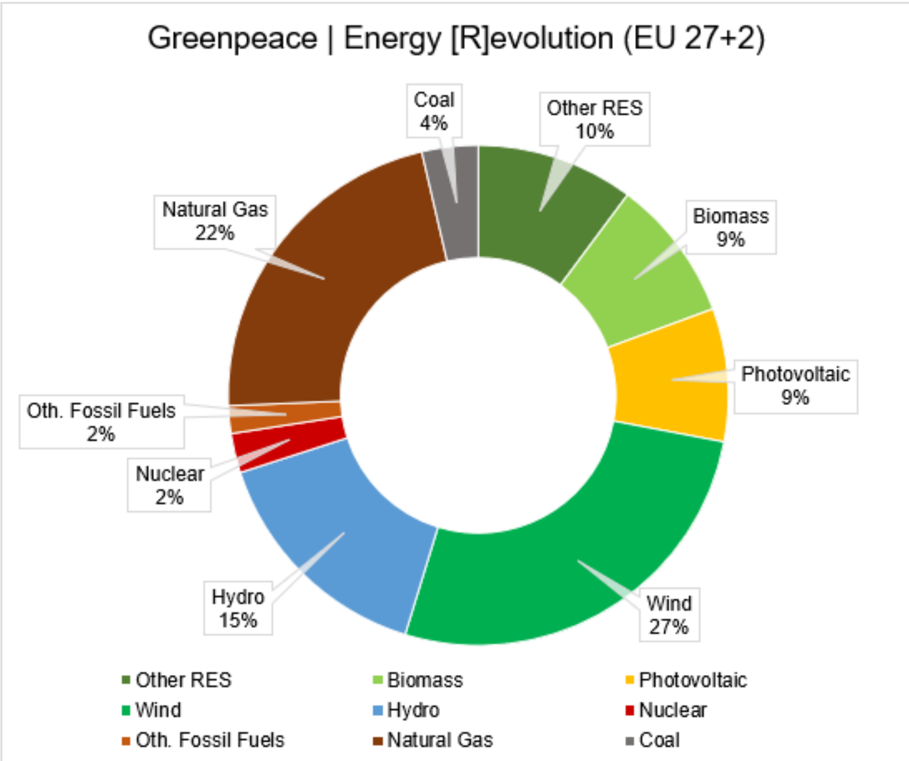

Figure 5.: Electricity Generation [MWh] 2030, in the Greenpeace Energy Revolution Scenario. Source: Teske, Sawyer, and Schäfer 2015, 116.

The Greenpeace Energy Revolution case assumes much lower electricity consumption in 2030 and 2050 compared to the TYNDP 2014, the Roadmap 2050 and the McKinsey scenario. Between the scenarios there is a difference of the projected demand of 550 TWh in 2030, overall this is around 15 per cent (Ackermann et al. 2014, 29; Feldhaus et al. 2010, 8 and 24; Roadmap 2050 2011, 28).

For the ambitious Energy Revolution Scenario a network capacity extension of additional 260.2 Giga Volt Ampere is necessary and 26.275 km of new transmission lines. This upgrade is quite moderate considering the high penetration of RES and very low nuclear energy capacity in this case. The reasons why this is possible, according to the authors of the scenario is, that more than half of the additional lines, namely 14,556 km are direct current lines and not the common alternating current overhead lines (Ackermann et al. 2014, 9). Furthermore lower electricity demand requires less transmission infrastructure.

Direct current lines do have the advantage that the whole transmission capacity is available for power transportation. In alternating current lines reactive power is taking up valuable capacity, and therefore, compensation devices have to be installed. According to Panos, for long distance transport, on land above 600 km and for sea cables above 30 km High Voltage Direct Current (HVDC) lines are more useful, as there are fewer thermal losses and the capacity for actual power consumed is higher than in High Voltage Alternating Current (HVAC) lines (Panos 2013, 318–19). Moreover, the problem of uncontrollable loop flows, which congest other transmission grids like it was the case in Poland, can be prevented with direct current lines (Berg Skånlund 2013, 25; Ackermann et al. 2014, 8).

The scenario identifies seven major routes where HVDC lines and increasing capacities are of major importance. First, the connection between Scotland and Southern England and second, the cross-border line between Spain and France is seen of major significance. Three important corridors are inland HVDC lines, namely from the French Coast, which has great wind potential to Paris, then from Germany's Northern Coast to the industrial centres in the Ruhrgebiet and Southern Germany and a connection between Southern to Northern Italy. The last two main corridors the Energy Revolution case had determined is from France to Germany, and from Italy to Germany (Ackermann et al. 2014, 17).

Europe as a whole is according to the 2030 Greenpeace Scenario totally autonomous in terms of electricity and will not need to import at all. Within the EU the major electricity exporters in this scenario will be Denmark, France, Spain, Poland, Croatia the importers on the other side Austria, Germany, Belgium, Finland, Norway and Italy (Ackermann et al. 2014, 46).

Another reason, the Energy Revolution Scenario argues, that makes it possible to keep transmission line expansion at a minimum, is efficient end consumer behaviour. Batteries have to cover 10 % of the photovoltaic system capacity and hence help to soften high peaks from solar energy. Demand side management and also electricity storage facilities in electric cars contribute to keep grid expansions at a minimum (Ackermann et al. 2014, 8). If the Energy Revolution Scenario also considers heat pumps and electric vehicles as storage possibility during peak loads, then the overall estimated electricity demand of 3830 TWh seems to be rather modest. Considering that in 2015 around 262.3 million cars were existing in the EU plus Norway and Switzerland (Statista 2018), assuming that they drive on average 12000 km per year this would amount to roughly 42 TWh of electricity, if 10 % of the cars are electric in 2030, and if 100 km consume around 13.3 kWh (Engel 2018).

With only a small percentage of electric vehicles, the projected curtailment rate of 2.8 % (Ackermann et al. 2014, 2 and 8) would likely increase in the scenario. Average curtailment in this case is already considerably higher, than in Europe today, and in comparison to the other three scenarios. Curtailment of electricity from RES is generally tending to increase with insufficient grid development.

3.2. McKinsey’s Transformation until 2050

The McKinsey Scenario begins at a quite different starting point. First of all it assumes a significant higher electricity demand: 4150 TWh by 2030 and 4900 TWh by 2050. The higher demand is due to the presumption that transport will be increasingly based on the usage of electric vehicles and the usage of electric heat pumps (Feldhaus et al. 2010, 8 and 24). Moreover, the whole scenario does not build on an electricity autonomous Europe, but aims at using the solar power potential of the Middle East and Northern Africa. Third the whole scenario set up is focusing on economical feasibility and on energy price developments.

For the purpose of climate change mitigation the aim of this scenario is to reduce CO_2 equivalent from 1.5 Giga tons in 1990 to 0.1 Giga tons in 2050 (Feldhaus et al. 2010, 19). Therefore, there are two cases drawn up, the "Clean" and "Green" one. Both fulfil the GHG reduction targets however only the Green Scenario one also fulfils the renewable energy target of 80 % by 2050 (Feldhaus et al. 2010, 51). Hence, the Green Scenario is used for comparison.

The graphic below, figure 6, shows that in 2030 the power generation is covered by nearly 30% from nuclear, by 36 % from mainly variable RES, 13 % will be covered by Hydropower, hard coal and lignite still contribute 12 % to the power mix and gas only 2 %. McKinsey assumed that 230 TWh, around 6 % will be imported from the Desertec Project in North Africa and in the Middle East (Feldhaus et al. 2010, 42). However the realisation of the solar energy project of the Desertec foundation is from a today's point of view very unlikely as the media had frequently pointed out in the last couple of years (Diermann 2018; *Frankfurter Allgemeine* 2014).

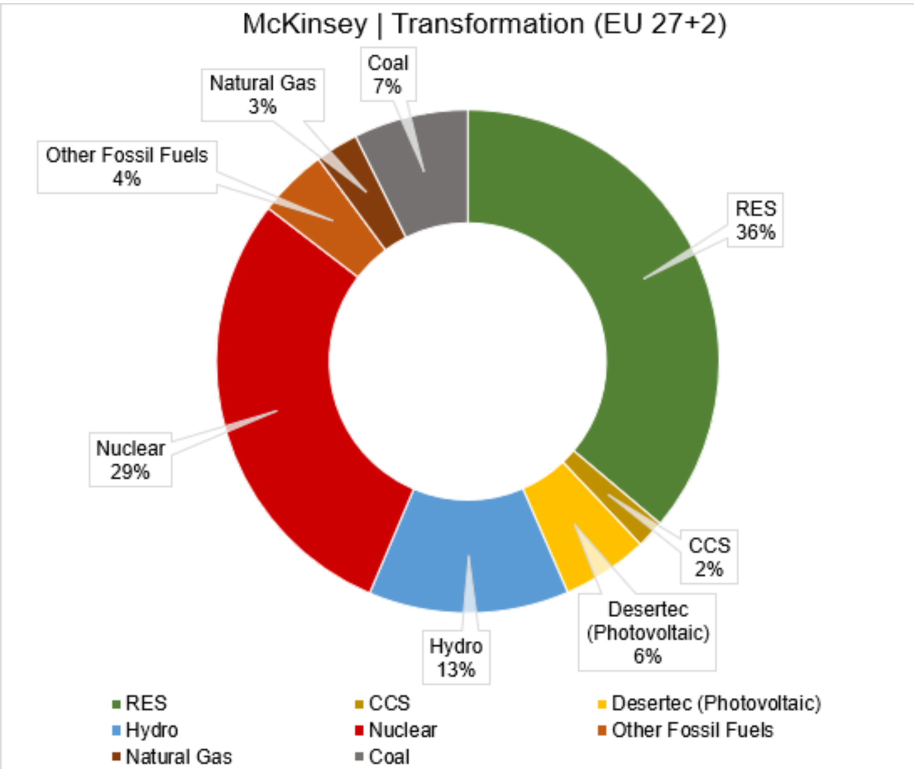

Figure 6.: Electricity Generation [MWh] 2030 in the McKinsey Green Scenario. Source: Feldhaus et al. 2010, 39.

20 years later, in 2050 the electricity generation mix entails around 13 % nuclear energy, so still 13 times more than in the Greenpeace Scenario for 2030. Around 14 % of the overall electricity demand is covered by imported solar energy. Coal and lignite would only produce a small share of 7 % and Carbon Capture and Storage technologies would be applied at 5 % of electricity production. It is assumed that in 2050 that CCS technologies are still more expensive than nuclear energy, and hence, there will only be a small amount of these applications used.

The McKinsey Green Scenario does not calculate any transmission line extensions but only considers net transfer capacities in GW. According to the ENTSO-e definition 'transmission capacity' is the same as the 'total transfer capacity', namely "the maximum transmission of active power in accordance with the system security criteria which is permitted in transmission constraints between the subsystems/areas or individual installations" (ENTSO-e 2013, 9). The 'net transfer capacity' is the available capacity for electricity trade. It is the 'total transfer capacity' minus the 'reliability margin' (ENTSO-e 2013, 7 and 9). The reliability margin is the reserve that TSOs need to have as safety capacity.

In terms of grid capacities McKinsey estimated that the net transfer capacity would need to increase in 2030 by two and a half times compared to the capacity available in 2010, namely to 544 GW. Until 2050 the net transfer capacity would need to increase even five and a half times, up to 1033 GW. The dominant electricity import areas are in central Europe, drawing up 37 % of their electricity consumption from other countries (Feldhaus et al. 2010, 39).

The McKinsey Scenario illustrates a number of pathways, were additional grid capacity will be necessary until 2030 and 2050, due to larger power flows. It highlights the cross-border between France and Spain as well as cumulative flows from Southern Italy to Western-central Europe and towards Germany. Moreover, it is estimated that more grid capacity will be needed, in order to connect South-eastern countries to Central Europe. The same is true for the Northern Sea, especially Denmark, but also for the United Kingdom. The area where most additional capacity will be needed until 2050 is according to the Green Scenario, the border between France and the Benelux States on the one side and Germany on the other, more than the triple capacity compared to the French and Spanish border.

The Green Scenario was built upon the goal, to find the most cost efficient solution for an energy system as a whole, under the given framework conditions of GHG reduction within the power sector (Feldhaus et al. 2010, 61). The goal was not to find the most environmental friendliest solution. Hence, the electricity constellation varies quite substantially, if compared to the Energy Revolution case. The McKinsey Scenario still includes a relative large amount of coal, especially compared to the Greenpeace Scenario where natural gas takes the most prominent place among the share of non-renewable energies. Coal is usually cheap and economically more feasible. Gas on the other hand, is often considered as the perfect compensation for a high penetration of RES, because it is very flexible in regard to short warm and cool down phases, and in terms of CO_2 emissions it produces much less than coal (Würfel 2017, 64 and 90).

3.3. Climate Change Foundation and its Power Perspectives 2030

The report, which was initiated by the Climate Change Foundation, presents the On Track Case that aims to outline realistic and cost efficient solutions and options for a decarbonised economy and draws a power sector scenario for 2030 that is on track with the 2050 GHG reduction goals (Roadmap 2050 2011, 7).

The On Track Case assumes an electricity demand of 4100 TWh in 2030 and a electricity generation mix that consists of 28 % variable RES, namely, 22 % wind energy, 6 % solar energy. The other RES account to 22 %, including mainly biomass and hydropower to an equal share and 1 % of geothermal energy. Nuclear energy is producing 16 % of the electricity demand in the On Track Case. Thermal power plants contribute with 34% towards the total electricity production and are divided into 25 % gas, 1 % coal and 7 % usage of CCS technology (Roadmap 2050 2011, 8).

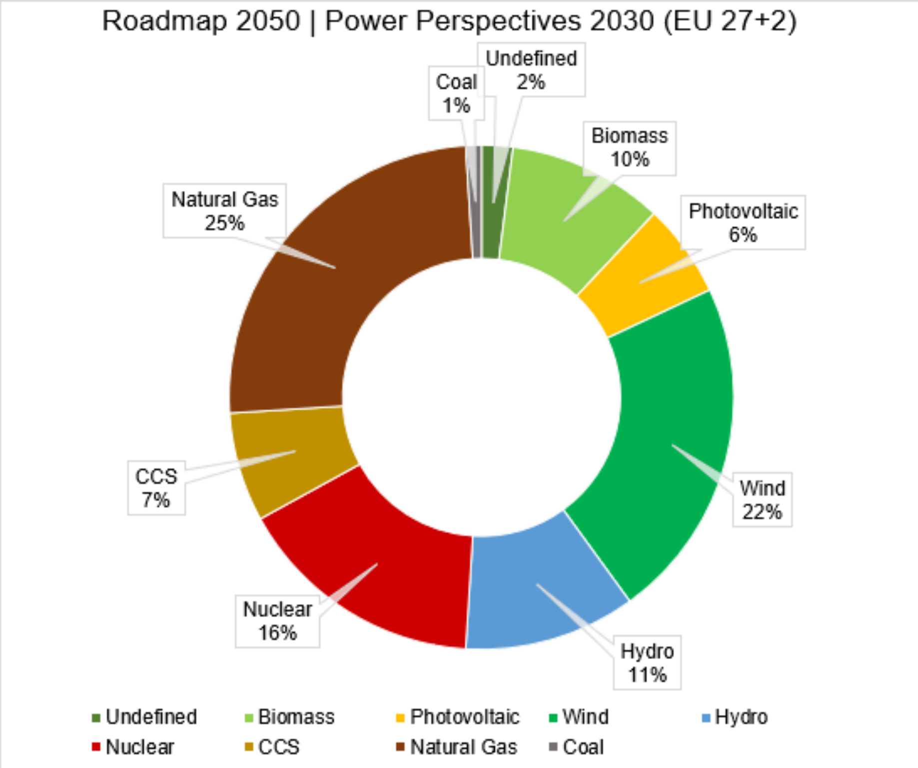

Figure 7.: Electricity Generation [MWh] 2030 in Roadmap 2050's Power Perspectives for 2030. Source: Roadmap 2050, 2011.

The report emphasises that "Building new infrastructure is the most cost – effective way to balance an increasingly decarbonised power system" and enables high penetration of RES, market integration and security of supply (Roadmap 2050 2011, 43). Grid development is calculated in transmission capacity or so-called 'total transfer capacity' and is defined as the 'net transfer capacity' plus the 'transmission reliability margin' (ENTSO-e 2013, 9).

It is forecasted to slightly more than double between 2010 and 2030, from 165 GW to 338 GW (Roadmap 2050 2011, 24 and 30). This number seems to be very low considering that McKinsey's scenario assumes a net transfer capacity necessary of 544 GW in 2030 for the same geographical area. However it also uses different initial starting data and supposes a 189 GW capacity in 2010 (Feldhaus et al. 2010, 45). This fact makes it increasingly difficult to compare the different scenarios with exact numbers.

The areas where grid capacity extensions are of most importance are cross-border connections, accounting to around 65 % of the additional capacity needed. The largest extensions will be required between the United Kingdom and Ireland, namely 13 GW, and between Spain and France around 11 GW will be necessary. However also within central European countries fundamental grid development is necessary, up front Germany, which needs to connect the North to rest of the country, closely followed by Great Britain that needs an increase of 15 GW capacity between Scotland and England (Roadmap 2050 2011, 30). Curtailment for this scenario is estimated to be quite low, namely at 0,5 % (Roadmap 2050 2011, 16).

3.4. ENTSO-e's Vision 4 of the Green Revolution

The Vision 4 was first established for the TYNDP 2014 and "reflects an ambitious path towards the 2050 European Energy goals, with 60 % of load supplied by RES in 2030" (ENTSO-e 2014a, 49). Overall energy demand is estimated at around 4220 TWh per year, however more than the 28+2 EU countries are considered, namely, Bosnia and Herzegovina, Montenegro, Serbia and Macedonia. The forecasted electricity demand for 2030 of the latter four countries does not exceed more than 100 TWh (ENTSO-e 2014a, 50 and 54). Therefore, Vision 4 is starting with a similar electricity demand prognosis as the Power Perspectives and the McKinsey scenario.

Less than a quarter of the electricity demand, 1000 TWh are still going to be produced from fossil fuels, whereas gas accounts for around 500 TWh. Nuclear is covering roughly the same amount as gas, namely a share of 13 %. Variable RES, consisting of solar and wind energy, take up the largest part in the energy mix, roughly a third of the total amount and hydropower and other non-intermittent RES account for a little bit more than a quarter, which is depicted in figure 8. (ENTSO-e 2014a, 54).

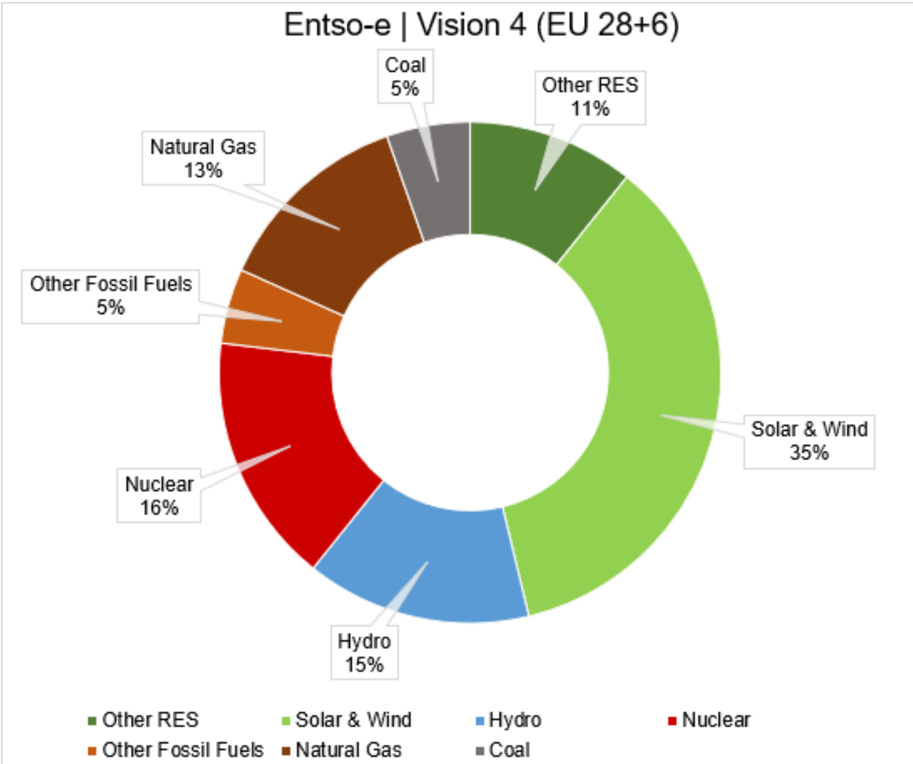

Figure 8.: Electricity Generation [MWh] 2030 in ENTSO-e's Vision 4 of the TYNDP 2014. Source: TYNDP 2014.

For Vision 4, as well as for the other three Visions, areas with major power flows were identified. In order to do so three different types of flows were analysed:

First of all "Generation Connections", that are transmission capacities that will be required to connect new RES or power plants to the grid. By 2030, power flows of more than 20 GW are estimated alone in the United Kingdom, especially to connect the offshore parks to the grid. But also in Southern France, Switzerland and Western North Austria at the border to Germany high flows of up to 10 GW are forecasted. The same accounts for three hotspots in the Northern Sea and in Southern Italy. Smaller amounts of grid generation connections, between 2 to 4.5 GW are needed in several areas at the Portuguese and Spanish Coast as well as in Ireland, Wales England and in Easter and Northern Europe (ENTSO-e 2014a, 61).

In the second category are power flows that are important for "Market Integration" and allow a higher share of electricity from RES to be traded over Europe. Power of over 10 GW capacity is estimated to flow on the border between the United Kingdom and

Continental Europe as well as on the North Easter Border of France to Germany and Belgium, and in Northern Italy towards all bordering countries.

In Vision 4 up to 10 GW of power flows are assumed between North and South Italy as well as within Germany and on the German borders to Belgium, Switzerland and Austria. Moreover, high flows are assumed in the Northern Sea between Denmark and Sweden, and on the Spanish French border as well as on the border between Bulgaria and Greece. Power flows in the range of 2 to 4.5 GW will occur between Portugal and Spain, on Germany's Eastern border towards Poland and the Czech Republic as well as in South and Eastern Rumania (ENTSO-e 2014a, 62).

In this scenario major flows are moving from Northern Europe to Southern Europe and from the Eastern Countries to Central and Southern Europe. These flow patterns are generated by areas with different RES potentials and consumer areas. Especially the Northern Sea, Ireland and Denmark have good wind potential whereas Southern Italy, Portugal and Spain benefit from solar energy (Brauner 2016, 63). Hydro pump storage plants are available in mountainous regions like the Alps but also in the Scandinavian countries (ENTSO-e 2014a, 62).

The third type of major power flows are concerned with "Security of Supply". If specific development projects are not realized than quality standards and reliable supply of certain areas are endangered. Especially highly populated areas in Central Europe could be affected, but also countries in the East of Europe which are not as well connected. However, if there is sufficient network capacity for major flows regarding "Generation Connection" and the "Integrated Market", then flows that a necessary for "Security of Supply" should not pose a problem (ENTSO-e 2014a, 61–63).

Considering the estimated power flow patterns, target capacities have been evaluated for Vision 4. Target capacities can be understood, as "the capacity above which additional capacity development would not be profitable" (ENTSO-e 2014a, 83), in the sense that more capacity would be uneconomical. It was pointed out that projecting them for 2030 is not so predictable. As cross-border target capacity heavily depends on a country's grid structure as well as on its electricity generation mix and they are frequently not used to there full capacity (ENTSO-e 2014a, 83).

For the energy transition the TYNDP 2014 concludes that around 43,000 km of new transmission lines will need to be built by 2030, in addition to the 300,000 km existing ones, if all "projects of pan-European significance" are being implemented. The projects are not completely in line with Vision 4. Hence, it is difficult to estimate an exact number in km, as certain parameters are still unknowns, like the exact locations of generation projects (ENTSO-e 2014a, 89).

Until 2024 the Network Development Plan foresees 41,000 km of new grid extension, almost half of them, 20,000 km being DC lines and the rest AC. The increased use of DC lines is especially due to connection of offshore wind parks and long distance lines between generation and consumption centres. Increasing HVDC lines will contribute to balance out transmission losses. Even though, like the Greenpeace Energy Revolution Scenario argued, HDVC have smaller transmission losses, converter stations cause on average 2 % loss of the electrical load. Hence, overall transmission loss equals each other out in the end (ENTSO-e 2014a, 69 and 88).

3.5. Differences and Similarities

Comparing these four different scenarios is not a simple task. There are various parameters that need to be defined and assumed in order to sketch an energy scenario for 2030. Driven by diverging objectives and guidelines, forecasts and outcomes vary significantly. Moreover, clear and comparable data is only available in some aspects of the cases. More often a general direction is indicated on how the grid and electricity generation would have to develop, if the EU aims to decarbonise the energy sector.

Also the forecasted data that is actually mentioned in the reports is hardly comparable. First of all, different geographical areas for the analysis were used, but also assumptions whether Europe is electricity autonomous as it is in the Greenpeace scenario or if it relies on imports, like it is the case in the McKinsey report vary. Second, certain important terms are not clearly defined. For instance the terms electricity mix can have various meanings like installed generation capacity, generated electricity or even consumed electricity. Therefore, it was sometimes not clear how the information has to be interpreted. Comparing future estimations of required total transfer capacity and net transfer capacity with transmission line extensions is not meaningful and rather misleading. Hence, the aim of this chapter is to extract the broader ideas and emphasis of the report in regard to grid development and compare them to each other.

Moreover, estimations of single parameters can change very quickly, for example the electricity demand for ENTSO-e's Vision 4 was significantly adapted only 2 years later, where suddenly the total electricity demand decreased to only 3700 TWh for the same geographical area (ENTSO-e 2015b, 31). Furthermore, it is interesting to see the scope of different starting points in terms of the constellation, in regard to the electricity production or achieved CO_2 reductions that are all still in line with the EU targets. This fact underlines that only few framework conditions have been set and defined for achieving a decarbonised economy. The different assumptions and starting points of the scenarios are illustrated in the figure 9 on the next page.

The underlying consensus and outcome in all scenarios is that until 2030 transmission network adaptations will be necessary, in order to integrate significant amounts of variable RES. Getting it down to clear numbers is more difficult, not only due to lacking definitions, in the sense of what is included and what not, but also due to different measurement units. For instance McKinsey and Roadmap 2050 rather focused on grid capacities [GW] and ENTSO-e and Greenpeace more on transmission line extensions measured in kilometres, as can be seen in figure 9. As mentioned before, exact numbers are misleading because likely changes in consumption patterns, electricity generation composition or locations of power plants have influence on grid development. Therefore, it is the common order of magnitude that is here considered and in the author's opinion most apposite and informative.

2030	ENTSO-e	Greenpeace	McKinsey	Roadmap 2050
Area	EU 28+6	EU 27+3	EU 27+2	EU 27+2
Demand	4220 TWh [2]	3830 TWh	4150 TWh	4100 TWh
CO_2 reduction: Power sector	78%	No Data	63%	65%
% RES [TWh]	60%	77%	55%	50%
% Variable RES [TWh]	35%	36%	No Data	28%
% Nuclear [TWh]	16%	2%	29%	16%
Total Installed Capacities	1700 GW	1484 GW	No Data	No Data
RES Installed Capacities	876 GW	1170 GW	No Data	No Data
Curtailment	0,90 %	2,80 %	No Data	0,50 %
Grid capacity	No Data	Additional: 260 GVA	Total: 544 GW as NTC	Total: 338 GW as TTC
New HVDC lines	20000 km	14556 km	No Data	No Data
New HVAC lines	21000 km	11719 km	No Data	No Data

Figure 9.: Overview of the four 2030 Scenarios

Sources: Feldhaus et al. 2010; Roadmap 2050 2011; Ackermann et al. 2014, ENTSO-e

[2] Around 100 GW can be contributed to the four countries that are not listed in the other three scenarios: Bosnia and Herzegovina, Montenegro, Serbia and Macedonia.

In terms of transmission lines, tens of thousands of km will be needed, exact numbers are depending on many uncertain parameters, like end consumer behaviour, storage facilities, CCS technologies or the share of nuclear. Additionally the importance of HVDC in this regard has been mentioned in all four reports. DC lines are important for offshore grid connections and long-distance transport and can replace higher numbers of AC lines. Grid capacity has, as especially, the scenarios of McKinsey and Roadmap 2050 suggest to increase by a couple of hundred GW.

Moreover, all cases have analysed major power flow patterns, or areas where major transmission capacity increase will be necessary. All scenarios agree on a major demand for capacity on the French and Spanish border by 2030 as well as on the importance of increasing connection between Germany and its neighbouring countries to the West. Where all other scenarios, apart from the Greenpeace's Energy Revolution see major power flows moving is between the UK and Continental Europe. Greenpeace, therefore, emphasizes the important connections within countries, especially in Italy, France, Germany and the UK. The latter two are also in line with the Roadmap forecast. McKinsey and Vision 4 on the other hand point out that large flows will flow between Denmark in the Northern Sea and Continental Europe.

All in all, it has been demonstrated that there are similarities between the four scenarios, which are based on different starting points. However that figures and numbers are difficult to indicate and compare. Moreover, what the scenarios have shown is, that there is not one single option of how the transmission network has to develop, but that there are various scenarios that include many uncertainties and unknowns. Another important factor that unites all these scenarios is that they use a top down approach, meaning that a scenario has been drawn, that aims at the overall *best* solution. However, generally it is the other way around, where national proposals and interests, predominantly, shape network development projects and plans.

4. EU-Policies on grid development

The previous chapter discussed four different scenarios that aim at outlining, in how far a future European grid needs to develop, and in what way it needs to adopt for the power sector to comply with the 2030 Climate Goals. This part of the thesis will focus on measures, the EU undertakes to push and speed up network development. The aim is to analyse how increasing demand for transmission capacity is addressed on a Union level. This is important, as to see, to what extent EU policies contribute towards reaching a European grid that is compatible with the integration of large shares of carbon free electricity generation.

The first subchapter is discussing to what extent the EU has the possibility and competence to address the issue for energy infrastructure development. In a second step, the two main pieces of EU legislation, for promoting electricity transmission will be analysed. This is Regulation (EC) No 714/2009 "on the access to the network for cross-border exchanges in electricity" that sets the legal basis for ENTSO-e and the TYNDP and Regulation (EU) No 347/2013 "for trans-European energy infrastructure", which regulates projects of common interest (PCI).

4.1. Setting the Scene

In the Treaty of Maastricht, in 1992, the EU was given the task to take "measures in the sphere of energy" (Boisseleau and Roggenkamp 2005, 1). According to Article 4 of the Treaty on the European Union (TEU) the EU shall have a shared competence with the member states in regard to the closely related areas of energy and trans-European networks. A shared competence follows the principle of subsidiarity, meaning that "the Union shall act only if and in so far as the objectives of the proposed action cannot be sufficiently achieved by the Member States […] but can rather […] be better achieved at Union level" (TEU 2012, Art: 5/3).

The Union’s mandate is further specified in the Treaty on the Functioning of the European Union (TFEU). “[T]he Union shall contribute to the establishment and development of trans-European networks in the area[…] of energy infrastructures.” Moreover, the operability and interconnection of national networks shall be promoted and isolated or peripheral areas shall be connected to the central European regions (TFEU 2012, Art: 170). In order to achieve these objectives the EU “shall establish a series of guidelines […], these guidelines shall identify projects of common interest.” The Union ”shall implement measures that may prove necessary to ensure the interoperability of the networks, in particular in the field of technical standardisation” (TFEU 2012, Art: 171).

In regard to energy, the EU shall take measures in order to “ensure the functioning of the energy market” as well as the “security of energy supply in the Union” and “promote energy efficiency and energy saving and the development of renewable forms of energy and promote the interconnection of energy networks” (TFEU 2012, Art: 194).

Communications of the European Commission can be a tool for promoting necessary development in the energy sector. For instance, in the Communication on strengthening Europe’s energy network, the European Commission promotes and stresses the need for member states to increase their interconnection capacities. There is the non-binding goal of 10 % cross-border capacity to neighbouring countries (COM (2015) 82 final 2015, 2). Member states should have a connection capacity with its neighbours that accounts to 10 % of the installed electricity generation capacity. A target that most member states are likely to reach, however, there a few worrying exceptions. Spain for instance, has currently an interconnection level of 6 % with no outlook of change until 2020 (COM (2017) 718 final 2017, 9-10).

However, the incorporation and connection of the Iberian Peninsula with Central Europe has been an important aspect in all 4 scenarios. The European Commission also aimed at addressing this issue with the *Madrid Declaration,* that has been signed in 2015 between France, Spain, Portugal and the European Commission, and fosters the need to increase capacity between Spain and France. The promotion of the Biscay Line project that connects France and Spain is central to the declaration (‘Madrid

Declaration' 2015). However, even if all these measurements aim at increasing interconnection, they are only of advising and supporting nature and are not binding legislation.

4.2. ENTSO-e and the TYNDP

The third energy package is legally binding. In there, the EU has taken up its mandate to harmonise rules and implement standards for a common European grid. ENTSO-e was founded with the EU Regulation (EC) No 714/2009 on conditions for access to the network for cross-border exchanges in electricity (Regulation (EC) No 714/2009, Art: 5). ENTSO-e was given the task to draft together with ACER and the European Commission the so called Network Codes in various areas like congestion management, transparency, security of supply, network connection rules or network security (Regulation (EC) No 714/2009, Art: 8). So far, eight legally binding Network Codes entered into force in three different areas. First of all, codes that aim at increasing market integration of electricity, second, Network Codes that set objectives to harmonise rules for grid operation, and last, connection codes that aim to foster a safe grid while "including renewables and smart consumption" (ENTSO-e 2017a, 17).

In the latter area, three Network Codes became legally binding in 2016. The code on requirements for grid connection of generators aims to harmonise rules for the connection of power generating facilities in transmission and distribution systems (Commission Regulation (EU) 2016/631). The second one is concerned with the connection electricity consumption facilities in transmission and distribution systems (Commission Regulation (EU) 2016/1388). The third code focuses on direct current lines, which are of increasing importance in long distance transport and in the connection of offshore wind parks as has been pointed out in the four scenarios. The regulation lays down rules for DC and HVDC connections and aims at ensuring appropriate application thereof (Commission Regulation (EU) 2016/1447).

These Network Codes are of great importance for a common and harmonised European transmission grid and electricity market that ensures the interoperability of the national power systems. The TYNDP is essential for the for transmission network development. As constituted in Article 8 of Regulation (EC) No 714/2009 the TYNDP is published by ENTSO-e every two years. Its objective is to identify and register regional transmission connections that are of relevance, either for commercial, or for security of supply reasons, and to give a future outlook for required grid capacities. The TYNDP is non-binding but an important instrument for determining necessary projects and depiction of capacity shortages. It represents the basis for the list of projects of common interest trans-European electricity infrastructure.

The first TYNDP was published in 2010. Since then, every two years ENTSO-e presents recent and future developments and a list of important infrastructure projects for the European grid. In the TYNDP 2018 almost 165 transmission network projects and additional electricity storage projects are listed (ENTSO-e Project List from TYNDP 2018). The year before 177 infrastructure projects were included in ENTSO-e's development plan, however, around 80 projects are intersecting both TYNDP, and are hence, listed in both plans (ENTSO-e Project List from TYNDP 2016).

The TYNDP includes projects of pan-European significance that are planned for the next 10 years. These are infrastructure projects that fulfil certain criteria. It only accounts for high voltage lines, where HVAC overhead lines must have a minimum of 220kV, and underground or subsea lines a minimum of 150kV. Furthermore it must be located, at least to some part, in one of the ENTSO-e member states and must contribute to the grid transfer capacity (GTC) across the network boundaries within the ENTSO-e area (ENTSO-e 2014b, 1–2).

The plan is developed in three major steps. First of all, a detailed assessment is taking place of how the energy and electricity situation may look like, ten to fifteen years ahead. This is not an easy task, as there are many different parameters that cause high uncertainties, as has been demonstrated also in the scenario analysis in chapter 3. The different energy outlooks are based on diverging assumptions. By the means of these outlooks ENTSO-e tries to model future energy situations and determines the scale of uncertainties. In a second step, likely electricity flow patterns are derived, and probable bottlenecks and capacity demands are determined. In the last step, all transmission infrastructure projects are analysed with a cost-benefit analysis (ENTSO-e 2018b).

This project selection procedure is in line with the Regulation (EU) No 347/2013 and Regulation (EC) No 714/2009 where it is stated that a “harmonised energy system-wide cost-benefit analysis at Union level” should be developed “for the preparation of each subsequent 10-year network development plan” by ENTSO-e (Regulation (EU) No 347/2013, Art: 11). TSOs have the chance to submit their transmission projects to be taken up in the network plan and only if their projects are listed in the TYNDP, the European Commission may consider it as a project of common interest. The transmission projects that are included in the TYNDP are being analysed against five major factors that are demonstrated in the figure 10.

⇒ The first indicator and probably the most significant one is Security of Supply. It is the predominant concern of every system operator and of utmost importance for society and economy. The project is assessed to which extent it contributes to reliability and security of the grid.

⇒ The second parameter is market integration. The contribution of the project towards enhancing and enabling European trade in electricity is assessed as well as the thereby generated socio-economic welfare. This is only possible, if congestion and curtailment is minimized due to sufficient GTC.

⇒ The next important consideration is to what extent the project further contributes to sustainability. This aspect is threefold, first of all if it enables the integration of RES, than the decreasing of CO_2 emission and last how it improves energy efficiency due to diminishing thermal losses. This factor is especially important in the light of the EU’s climate targets.

⇒ Technical conditions of the project are also being assessed in the cost benefit analysis. On the one hand resilience whether the transmission line is able to cope with extreme conditions and on the other hand flexibility in the sense that the project has a positive contribution in different future scenarios.

⇒ The last factor that is analysed is the social and environmental impact of the project.

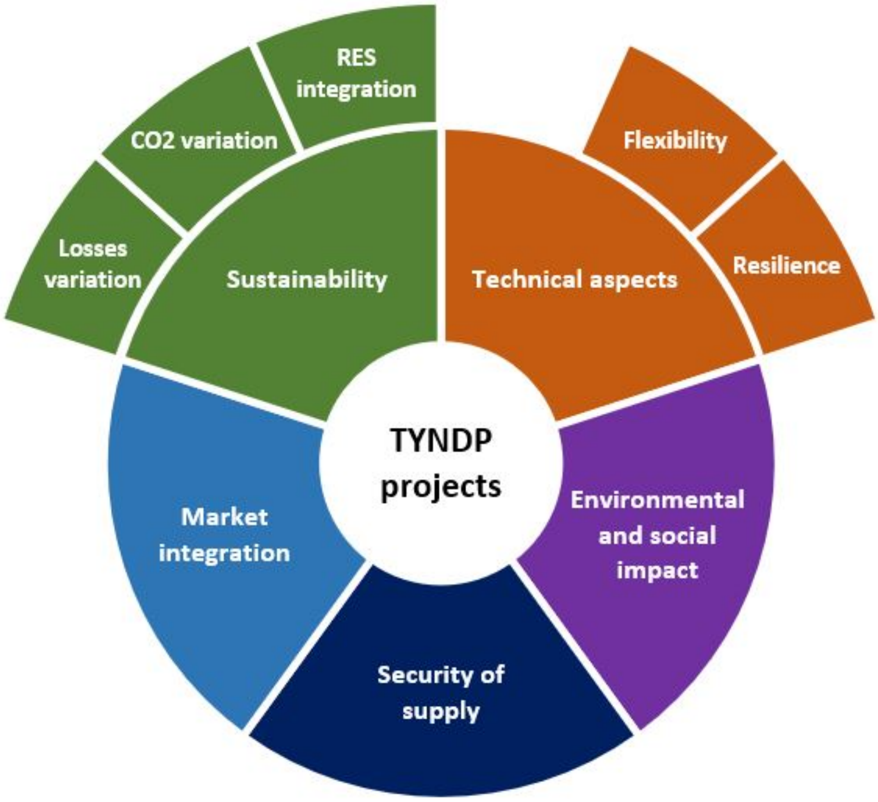

Figure 10.: TYNDP projects assessed via a Cost-benefit analysis.
Source: Executive Summary: TYNDP 2016: Chapter 1.11.

The transmission infrastructure projects that are included in the TYNDP are, therefore, at least in one of these five major aspects beneficial. However, not all transmission infrastructure projects are necessary for the decarbonisation of the power sector, but foremost of importance for the integrated market. Even though an integrated market, obviously helps to use electricity more efficiently and can contribute to balance intermittent energy sources as has been pointed out by (Bahar and Sauvage 2013).

The TYNDP is an overall assessment of projects that are benefiting the European electricity grid in one or the other way, however, there is no guarantee for the successful implementation of these projects. The recent years a considerable amount of projects of pan-European significance, or projects parts which are referred to as investments, were cancelled, rescheduled or delayed. In December 2016, already a quarter of the investment projects were known to be off the intended time schedule. A year after the TYNDP 2014, only 67 % of the investment projects were on track with the implementation procedure, and 33 % were facing difficulties. Hence, these projects were rescheduled, cancelled or were dealing with delays. For the TYNDP 2012, the scenario was similar (ENTSO-e Project List from TYNDP 2012, 2014 and 2016).

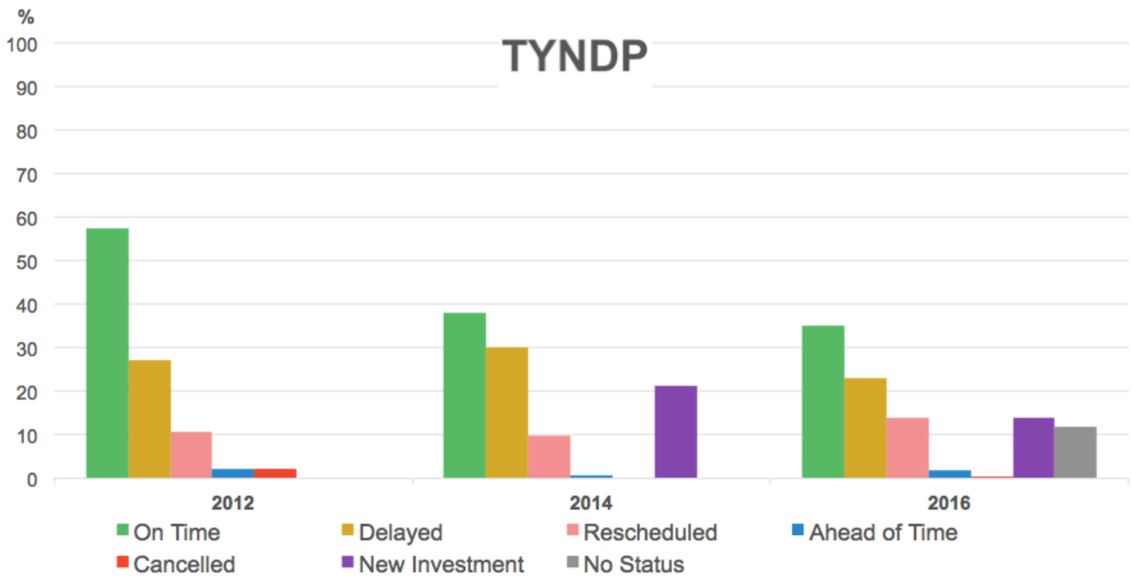

Figure 11.: TYNDP project investments and their progress one year later.
Sources: ENTSO-e. Project List from TYNDP 2012, 2014 and 2016.

The ENTSO-e monitoring report 2015 analyses the reasons for project delays, cancelations and reschedules. In the case of investment project cancelation, which amounted to overall 3 %, the main reason is alterations on consumer or production side that causes transmission projects to be dispensable. Another reason is that some investments are incorporated in other projects or that there are unsolved financing issues (ENTSO-e 2015a, 7).

By far, most of the projects of the TYNDP 2015 are delayed during the permitting process. This is a pattern, similar to other TYNDPs. Also public opposition is a significant factor that needs to be considered, influencing permit granting as well as during other stages of the process. Another issue that causes setbacks are often problems with the acquisition of land premises for transmission lines, or financial uncertainties. Moreover, delays can be caused by any unexpected events that demand changes of the original route or technical aspects, however, these cases contribute only a small percentage to all delayed projects (ENTSO-e 2015a, 7–8).

Uncertainty is the dominant cause for project rescheduling. This corresponds to the overall situation in the power sector. Long-term investments are needed, but then there are many unknown parameters that make investments high risk and vulnerable to changes. Planning data input often needs to be modified during the further development of the project, and parameters like locations of electricity generation or altering electricity demand. Moreover, only after a certain planning phase the actual commission date can be determined with more accuracy (ENTSO-e 2015a, 8–9). Long-term projects are rescheduled in order to decrease uncertainty.

4.3. Projects of Common Interest

The idea and concept of the Projects of common interest (PCI) is to facilitate the implementation of energy infrastructure projects and to reduce the cancelation, delay and rescheduling rate of important constructions for the European energy network. The regulation covers projects, necessary for electricity as well as gas transportation. For the purpose of this thesis, electricity transmission infrastructure will be the focus of discussion.

The "Regulation on Guidelines for trans-European Energy Infrastructure" (Regulation (EU) No 347/2013) is the main piece of legally binding EU-policy on grid development and sets up the Union's most important instrument for promoting trans European energy infrastructure, namely the list of PCI. It has entered into force in 2013 and is targeting the problem of lacking transmission capacity needed for an integrated market as well as for decarbonising the power sector. It emphasizes the need to upgrade the European grid, to further interconnect the transmission network and to incorporate renewable energy. In order to do so the objective of the guideline is fourfold (Regulation (EU) No 347/2013, Art: 1):

- The identification of projects of common interest.
- The facilitation and "timely implementation of projects of common interest"

- Providing incentives for projects of common interests.
- The determination of criteria of projects of common interest for eligibility for EU funding.

ENTSO-e has mentioned in one of the insight reports 2016, the importance of PCIs for the European transmission network development, as it promises to reduce the time of permit granting and eases investment costs (ENTSO-e 2016a). The concept of PCI almost seems like a magic bullet, if it enables to secure the timely implementation of projects as well as contributing to set incentives for projects promoters and providing additional financial support. How the trans-European network energy infrastructure regulation (TEN-E regulation; Regulation (EU) No 347/2013) is pushing those objectives, and how the implementation looks like, is analysed in more detail.

4.3.1. Identification of projects of common interest

The TEN-E regulation lays down the criteria for infrastructure transmission projects to be accounted as a PCI in Article 4. The first condition of a PCI is that the project is necessary for at least one priority corridor or area, which is listed in Annex I. For electricity transmission there are four geographical corridors, and one thematic area defined. The first corridor is the “Northern Sea Offshore grid” that focuses on integrating offshore parks “in the North Sea, the English Channel, the Baltic Sea and neighbouring waters” and interconnecting them with consumption areas (Regulation (EU) No 347/2013: Annex I). The second and third corridor are aiming at fostering North and South connection in Western as well as in Eastern Europe. The fourth corridor aims at interconnecting the Baltic States and tries to integrate them more into Central Europe. The last important one is the thematic area of electricity highways that concerns all member states.

The Second criterion is that the retrieved possible benefit of the project outweighs total cost in the long run. A cost-benefit analysis is already done by ENTSO-e for the TYNDP. The third important aspect that needs to be fulfilled is that the project either is “directly crossing the border of two Member States or more” or a country that is part of the European Economic Area (Regulation (EU) No 347/2013, Art: 4/1/c), or it is located in one member state but "increase[s] grid transfer capacity […] for commercial flows at the border" (Regulation (EU) No 347/2013, Art: 4/1/c and Annex IV).

A PCI must be of significance for at least two countries within the European economic area, but additionally it shall also contribute to one of three major policy areas, namely market integration, sustainability and security of supply. An infrastructure project that contributes to market integration needs to reduce bottlenecks and be able to increase flexibility and market integration. The category sustainability covers projects that are able to "integrate renewable energy into grid" and to transmit it to "major consumption centres and storage sites" (Regulation (EU) No 347/2013, Art: 4/2/a). With Security of supply it is understood that the PCI adds to grid reliability and secure operation in the system.

The selection of the projects starts with TYNDP prepared by ENTSO-e. Only projects included in the TYNDP can be eligible for the PCI list. Then project promoters submit their project to the National Regulatory Authority (NRA) for electricity. In Austria it is *E-Control* and in Germany the *Bundesnetzagentur.* The regulatory authorities examine, if all the criteria of Article 4, mentioned above are fulfilled. In a next step the submitted project is evaluated in one of the regional groups. All in all, the TEN-E regulation establishes twelve regional groups, for electricity transmission, however, only four groups are of significance, namely those that are reflected above in the priority corridors.

Each group must rank the projects and rate their importance for the region and appoint a list. Decision-making power of each regional group lies by the member states and the European Commission (Regulation (EU) No 347/2013, Art: 3/3). ACER has than the possibility to give an opinion on the group lists and examines the consistency of the cost-benefit methodology. In the final step the European Commission then adopts, as a delegated act, the list of PCIs.

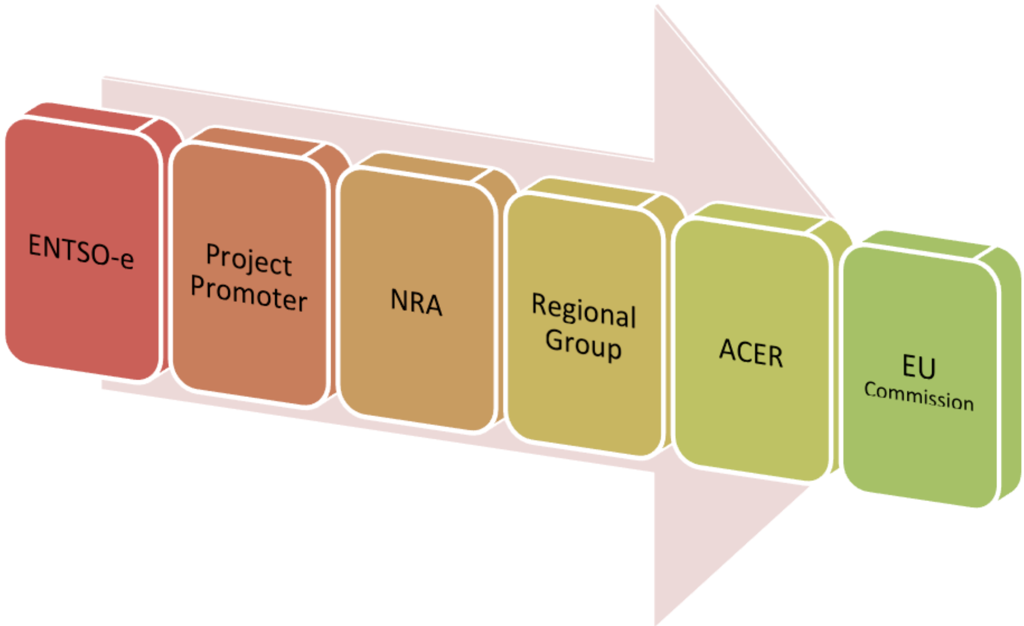

Figure 12.: Selection process of the PCI list. Source: (E-Control 2018)

So far, the European Commission adopted three lists: the first one was published in 2013, the second one in 2015 and the last one in 2017. The first PCI list included 132 electricity transmission and storage projects, the one published two years later entailed 108 projects including storage projects, but excluding gas infrastructure (ENTSO-e 2016a) and the latest list includes almost 102 transmission infrastructure projects (Commission Delegated Regulation (EU) 2018/540, Annex VII).

Having a closer look at the PCI list of 2015 reveals that for certain cross-border connections a significant upgrade is planned. For instance on the French-Spanish border there are two PCI planned that would add more than 6 GW transmission capacity until 2030 (ACER 2017, Annex III). The importance to connect the Iberian Peninsula to Central Europe has been pointed out in all scenarios. Also between Portugal and Spain interconnection capacity is supposed to increase by around 2.5 GW. Another important connection that has been emphasized is between Germany and its Western neighbours. PCI projects aim at contributing around 2.5 GW by 2030. Additional 4 GW transmission exchange capacity is aimed to be added between Denmark and Germany within the same period (ACER 2017, Annex III), a connection that is mainly in

McKinsey and Vision 4 report of importance, as has already been pointed out in chapter three. Apart from the Greenpeace Scenario all agree on the necessity to better integrate the United Kingdom and Continental Europe. The PCI list 2015 has listed projects accumulating to approximately 2.5 GW exchange capacity between the island and France and Norway (ACER 2017, Annex III).

The Greenpeace, the Roadmap, and the Vision 4 scenarios also pointed out the necessity of inland connections especially in Germany and in Italy. Two internal HVDC lines in Germany with a capacity of 2 GW and 4 GW are both planned to be commissioned in 2025 (Bundesnetzagentur 2018a; European Commission 2016)[3] and other cross-border lines leading to the Czech Republic, Poland and Austria (ACER 2017, Annex III). For Italy there are no internal PCI, but many interconnections to the North that are crossing borders to Austria, France or Switzerland (ACER 2017, Annex III). The PCI are often represented in areas that are mentioned at least by one of the scenarios as very important, however they hardly ever reach the indicated amount of capacity.

4.3.2. Timely Implementation

The delay and rescheduling of infrastructure projects is often a barrier to necessary transmission network development. The TEN-E regulation seeks to ensure the timely implementation of PCI. In Article 5 it obliges project promoters to "draw up an implementation plan" (Regulation (EU) No 347/2013, Art: 5) with a time schedule for four different phases; feasibility study, approval of the NRA, permit granting phase and for construction and commissioning. Every year project promoters shall give report on the progress and indicate reasons for delays. If a PCI suffers from severe difficulties during the implantation phase causing delays, the Commission may nominate a European coordinator who shall assist in promoting the project and be able to advise the parties involved.

---

[3] PCI numbers 3.12 and 2.10

Most of the delays in transmission infrastructure projects are caused during the permit granting phase, as has been pointed out by the TYNDP projects. Therefore, PCIs are entitled to a "priority status" (Regulation (EU) No 347/2013, Art: 7). Member states are also obliged to grant PCI "the status of highest national significance possible" under their respective national law. During the permit granting all authorities shall work as efficiently and rapidly as possible within the legal requirements. Especially in regard to the Environmental Impact Assessment member states shall streamline and harmonise their procedures.

According to the TEN-E regulation, the permit granting procedure shall take place in two phases (Regulation (EU) No 347/2013, Art: 10). Article 8 compels member states to designate a single competent authority for the permit granting process, which greatly simplifies the process for project promoters (ENTSO-e 2016a). The first phase begins with the "start of the permit granting process" and ends with the "acceptance of the submitted application file by the competent authority". The time period for this phase shall be limited to two years. The second phase, which shall not exceed 18 months, covers the time span from the moment of application acceptance until the point where a "comprehensive decision is taken." All in all, the permit granting process shall therefore, be limited to at timeframe of three years and six months (Regulation (EU) No 347/2013, Art: 10).

Intentionally 53 electricity projects with PCI status were planned to be ready for commissioning by 2020. However, until now the PCI concept is not as promising as its objective is. By 2017 around 53 % of the projects were on time or ahead of time, a better quota than the projects in the TYNDP 2016 and 2014, as demonstrated in figure 11. A large share, however, still faced delays or rescheduling, 31 % and 14 % respectively, as can be seen below. The trend is confirmed that most of the project delays are still caused during the permitting phase (ACER 2017, 19). Also the two major HVDC transmission lines within Germany contributing 6 GW of transmission capacity face delays due to planning the alternative of an underground cable, which receives more public acceptance (ENTSO-e Project List from TYNDP 2016).

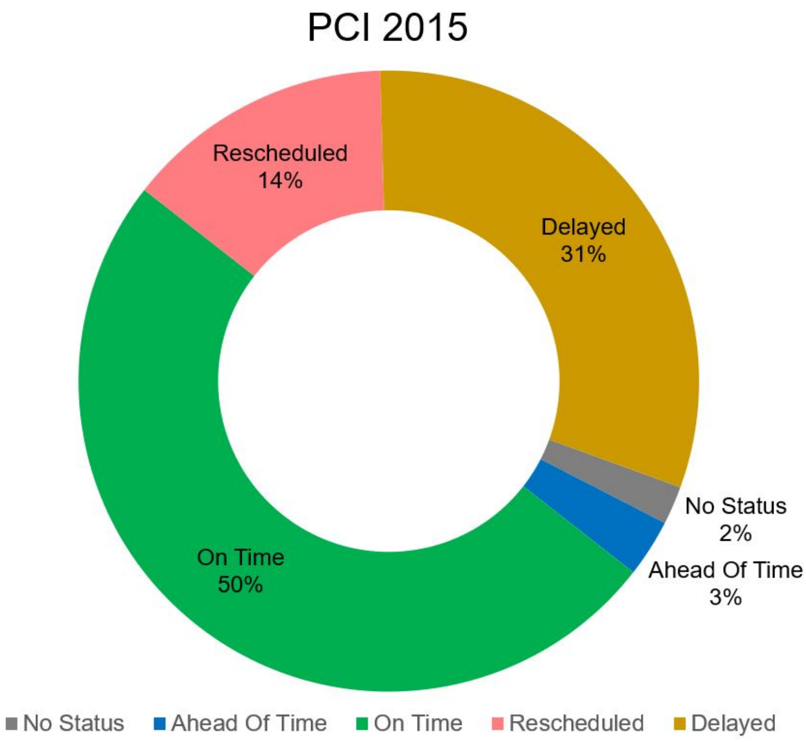

Figure 13.: PCI 2015 and their progress in 2017.
Source: ACER 2017, 19.

4.3.3. Cross-Border Cost Allocation and Incentives

Cross-border interconnections are of utmost importance for the integrated electricity market. The European Commission has formulated the goal of 10 % interconnection capacity by 2020 and 15 % by 2030 (COM (2017) 718 final 2017, 9 and 11). These targets should be achieved with the means of PCI. Cross-border projects often bare higher risks for project promotes during “the development, construction, operation or maintenance” of the project (ENTSO-e 2016a). Promoters are hence, more reluctant to invest in cross-border electricity infrastructure, especially if cost recovery is uncertain (Sattich 2015, 80).

Generally, the costs for PCI have to be carried by those countries, which benefit from it. However, if the total costs are higher than the expected gain from the project, then a cross-border cost allocation (CBCA) may be applied. In the year 2016 the project promoter of six PCI submitted requests for a CBCA. All in all ten applications have been issued from the 2015 list until July 2017 (ACER 2017, 36). This possibility is laid down in Article 12 of the regulation.

Moreover, Article 13 of the TEN-E regulation directly focuses on incentives for project promoters that incur […] higher risks for the development, construction, operation or maintenance of a project of common interest […] compared to the risks normally incurred by a comparable infrastructure project." In such a case NRAs must assure that "appropriate incentives are granted" (Regulation (EU) No 347/2013, Art: 13). Therefore, each NRA is asked to draw up a guideline that elevates a risk assessment methodology and mitigation measure thereof. However as the ACER report on the progress of PCI has pointed out, only a small number of four have so far applied for this possibility and only very few show incentives to do so (ACER 2017, 37–38). The reason for the low number of applications may be explained by the relative small scope of how, additional incentives can be granted. Furthermore, the effectiveness of these measures is limited, considering the political and economical landscape.

4.3.4. Financial Assistance

The TEN-E regulation provides the legal basis for financial assistance to PCI that would otherwise not be economical feasible. In Article 14 a set of criteria is laid down for electricity transmission infrastructure projects considered as PCI that need to be fulfilled in order to qualify for financial assistance in form of grants for studies and for works (Regulation (EU) No 347/2013, Art: 14). Grants for studies for instance help to finance feasibility or environmental studies and are available for all PCI, listed in one of the priority corridors.

For a project to be eligible for receiving funds for work, it must fulfil a number of criteria. First of all, a cost-benefit analysis needs to assure that the project will cause "significant positive externalities such as security of supply" (Regulation (EU) No 347/2013, Art: 14/2/a). Secondly, the transmission line must have "received a cross-border allocation decision" and aspires to deliver cross-border benefits as well as safety in "grid border operations" (Regulation (EU) No 347/2013, Art: 14/2/b). The third criterion that needs to be fulfilled, is it that “the project is commercially not viable, according to the business plan and other assessments carried out” (Regulation (EU) No 347/2013, Art: 14/2/c).

The main fund that provides financial assistance for electricity transmission infrastructure and other PCI is the Connecting Europe Facility (CEF). The Regulation (EU) No 1316/2013 established the fund in 2013 and indicates conditions and methodology for the European Union support for investments for PCI in transport, telecommunication and energy. The CEF shall, as also pointed out in the TEN-E regulation, support infrastructure projects that either contribute to further integration of the internal energy market or enhance security of supply or help towards a more sustainable development in integrating intermittent energy sources (Regulation (EU) No 1316/2013, Art: 4/3).

The total budget that is allocated to the CEF for the six-year period from 2014 until 2020 is around 33.42 billion euros. The largest share is reserved for the traffic transport sector with 26.25 billion euros. To the energy sector are 5.85 billion Euros allocated, where as the majority is reserved for gas infrastructure projects. The remaining money is kept for the telecommunication sector (Regulation (EU) No 1316/2013, Art: 5). Concerning electricity PCI in the four priority corridors around 35 % of all projects, namely 38 have so far submitted applications for grants either for studies or for work or both between the year 2015 and 2017. And a dozen more intend to apply for it in the next years (ACER 2017, 39).

Until 2017 the CEF fund has spent 1.6 billion euros for gas and electricity infrastructure, including smart grids. In regard to the PCI in the electricity sector 43 so-called actions were financially assisted (European Commission 2017). Some projects received support twice, namely for studies and for work. However the majority of actions that were supported were studies. All in all 43 actions were financed in the electricity sector; 36 of them were grants for studies and only seven grants for work were distributed. Altogether around half a billion euros were spent on electricity transmission infrastructure projects (European Commission 2017).

The European Commission mentions an amount of 140 billion euros, on its website, that is estimated to be necessary to get the European electricity grid in shape, to guarantee security of supply and to meet capacity demand (European Commission 2018a). Considering large amount, the financial assistance of half a billion euros, provided via the CEF fund to electricity transmission infrastructure projects, seems like a drop in the ocean.

5. Evaluation and Challenges

The previous chapter looked at how the European Union addresses the demand of increasing transmission capacity, in the light of the four 2030 energy scenarios, outlined in chapter 3. This part of the thesis aims at bringing the scenarios and EU-policies closer together in evaluating, to what extent the EU measures for grid development are contributing to reach the renewable energy targets.

Strengths and the weaknesses of the above analysed EU-policies are outlined. The analysis follows along four key issues that impact grid development. The major points addressed are the bottom-up approach that shapes development and project plans, then market unbundling as a cause for inefficient infrastructure development, third the lack of clear long term energy policies which contributes to uncertainty in planning, and last the permitting process that is the major reason for project delay.

5.1. Top-down or Bottom-up

The scenarios established a setting for 2030 where at least 50 % of the produced electricity comes from RES. Then they indicated how a common European grid, will have to be designed to integrate large amounts of RES. A situation was generated that is beneficial for a common Union, but one that does not favour individual solutions that are best for single member states. For these future outlooks a top-down approach was used. It is analysed where major electricity flows are likely, and hence, where additional infrastructure is needed. There are four different outcomes, because every scenario used different input data, in regard to how much nuclear is used or how the RES composition looks like and where these sources or located.

The EU however, does not have such competence in order to design the common electricity infrastructure. The Union may only promote the interconnection of countries and the integration of isolated areas and shall merely contribute in the development of a European infrastructure network for electricity. The establishment of the European grid is therefore based on a bottom-up design, where member states develop their own Network Development Plans and submit their infrastructure projects to ENTSO-e to be included in the TYNDP, which is then the basis for the list of PCI. National development is determining, how a common European grid looks like, not a single designer on the top.

National projects and interests are shaping the European Union policies and are the basis for development, rather than overall benefit and efficiency. Projects that are included on the list of PCI are of European significance and common interest, however, if they are not resubmitted by the project promoter or cannot be implemented due to reasons on a national level then they cease to be PCI. (Regulation (EU) No 347/2013 Annex C (2015) 8052 final, 3) Therefore, if infrastructure is utterly needed to reach the Union's goals of market integration, security of supply or the decarbonisation of the power sector, the EU has not the competence to decide whether projects are realised or not. The decision-making authority remains with the member states concerned, by the infrastructure project. The Union can assist in project development and promotion, as done for instance in the Madrid Declaration, where an agreement was set up between France, Spain, Portugal and the European Commission in 2015 to better connect the Iberian Peninsula to Continental Europe ('Madrid Declaration' 2015), but cannot force member States to build new transmission lines.

The interconnection between France and Spain is one of the most congested ones in Europe. Even if the all projects planned, are implemented with the political will demonstrated in the Declaration, the connection capacity rises to 8 GW by 2030 (ENTSO-e 2016b, Annex: 1.12.7). This is a capacity increase of around 6 GW (ACER 2017, Annex III). The development is heading in a similar direction as outlined in the scenarios, but capacity increase is not sufficient, if compared to the scenarios. For instance McKinsey foresees the necessity of a 8 GW connection already by 2020 which is further strengthening to 20 GW by 2050 (Feldhaus et al. 2010, 45). The Greenpeace Energy Revolution also foresees an interconnection at the border with a capacity of 20 GW (Ackermann et al. 2014, 45), whereas the Roadmap for 2030 has modelled a capacity of 11 GW (Roadmap 2050 2011, 30).

Project Plans are partly covering the needs outlined in one, or in all of the scenarios, but often not to the full extent. However, this is difficult to compare, as the four outlooks themselves are greatly varying. Nevertheless, the energy scenarios are built on hypothetical conditions, but not on political realities where member states pursue their national interests and not primarily Union goals. For the EU to be able to implement policies that could guarantee sufficient grid capacity, it would need more competence in the area of trans-European infrastructure.

5.2. Unbundling for the Free Market

Electricity grids are natural monopolies and therefore, problematic in a free market. With the mean of the third energy package the European Union aimed at further integrating and liberating the energy market. Ownership unbundling was one of the mechanisms to achieve the latter. The goal of the economical and, or administrative separation between electricity generators and TSOs was the prevention of discriminating access to transmission networks (Sokołowski 2016, 177–78).

Unbundling however, has contributed to inefficient network development, as electricity producers do not need to consider grid conditions when choosing locations for power generations. Transmission costs are hence, hardly taken into account when decisions are taken on locations. Generators are not involved in transmission network development anymore and therefore, do not calculate transmission costs in this regard (Haucap and Pagel 2013, 236). TSOs have to pay the expenses for necessary grid upgrades due to geographical changes in generation patterns. Whereas an operator in charge of electricity generation and transmission would hence, push for the best economic solution at least possible cost, for both grid and generation expenses (Haucap and Pagel 2013, 237).

TSOs are receiving fees for their services. The tariffs, however, are due to the monopoly position monitored by the national regulatory authorities. According to the EU "Regulation on conditions for the access to the network for cross-border exchanges", TSOs can set charges that "take into account the need for network security and reflect actual costs incurred, insofar as they correspond to those of an efficient and structurally comparable network operator“, however, “[t]hose charges shall not be distance-related” (Regulation (EC) No 714/2009, Art: 14/1).

This provision is aimed at enabling market competition, but not so much at using grid transmission capacity as efficient as possible, even though it is increasing in high demand. However, on the other hand, unbundling has been important for preventing discrimination. Even Greenpeace pointed out its importance for securing market access for new renewables (Ackermann et al. 2014, 11). Nevertheless, Union policy on trans-European electricity infrastructure should not only focus on encouraging additional transmission capacity, already something that presents difficulties, but also on the efficient usage thereof.

5.3. Uncertainty and High Risk

The TYNDPs and the lists of PCIs have demonstrated that large shares of planned projects are rescheduled. Already a year later around 10 % to 15 % of the listed projects, as demonstrated in figure 11 and 13 are rescheduled. Among the main reasons indicated by project promoters for rescheduling are the prioritising of other transmission projects, or input data changes as well as changes on the generation side, or project relocations (ACER 2017, 24). These reasons can be summarised under the heading of uncertainty regarding electricity needs and future political or technological development.

Uncertainty leads to higher risks. On the European Union level there is no clear policy on how the energy sector needs to develop until 2030 and beyond, apart from the aim of decarbonisation. Nevertheless, how this decarbonisation shall look like in detail is still an open question. Also the Greenpeace, the McKinsey and the Roadmap scenario as well as the Vision 4 have demonstrated this. All of them respected the decarbonisation goal in the energy sector by 2030 outlined in the EU Commission’s Communication on A Roadmap for moving to a competitive low carbon economy in 2050 (COM (2011) 112 final 2011, 6), but greatly differed in terms of the generation mix, estimated electricity demand and hence, the determination of major electricity flows varied from one scenario to the other.

Transmission infrastructure projects are long-term projects that need around 10 to 15 years from planning until commissioning (ENTSO-e Project List from TYNDP 2012; ACER 2017, 25). If there is uncertainty or missing legally binding policies of how the future power sector will look like, project promoters are reluctant to advance with their plans. They rather reschedule and wait until there is more certainty and data available, which helps to contribute in reducing investment risks.

The uncertainties are dual in nature, on the one hand the lack of clear and detailed policies for 2030, and on the other hand possible technological development. The EU has formulated the goal of 27 % energy consumption of RES. This target does not indicate how high the electricity consumption will be, whether the EU is autonomous in electricity generation or not, or how large the share of nuclear will be. Moreover, uncertainties in regard to the regional locations of future RES exploitation are also persisting. For instance, no connection targets have been defined between continental Europe and the UK and Ireland due to that reason (ENTSO-e 2016b, Annex 1.12.1).

However, also new technologies have the potential to rough up the future energy mixture. For instance, the Carbon Capture Storage technology has been frequently mentioned as a possibility to contribute in CO_2 reduction, especially in regard to 2050 climate targets. The idea behind CCS is that carbon coming from fossil fuel burning is captured and either stored at the bottom of the ocean or deep in the ground in former oil reservoirs. The CCS could contribute to CO_2 removal in the atmosphere, if the carbon is safely stored and possible leakages are prevented. The high energy consumption of the technology is however problematic (Umweltbundesamt 2018). Nevertheless, it is often argued that without such technologies CO_2 targets will not be met (Leeson et al. 2017).

To what extent the power sector can count on CCS is not yet predictable. To what degree CCS technology can be deployed in the near future depends on several factors, like commercialization, availability as well as on public acceptance thereof (Oberthür and Dupont 2015, 9). The McKinsey Scenario for example already made use of it in its forecast, however, the others did not. Either way such technologies influence the operation of the power sector and provide another source of low carbon and non-intermittent energy. Hence, the requirements on the transmission grid are others than without widely CCS technology application.

Another new technology that can contribute to reaching decarbonisation targets is Power to Gas. It has the potential to balance the variability of many RES and can contribute, next to batteries and water storage power plants to store electricity in form of gas. However "the main drawbacks of Power-to-Gas are a relatively low efficiency and high costs" (Götz et al. 2016, 1372). These disadvantages make it difficult to determine at which point this technology becomes economical and broadly available on the market.

Even though CCS and Power to Gas have a great potential in contributing towards reaching the climate change goals, they also add uncertainty. The different outcomes of the scenarios in chapter 3 have shown that there are many unknown parameters involved in planning a European transmission that is able to integrate low carbon electricity. Unknowns cause higher investment risks for project promoters and this again can result in rescheduling or even to a lack of planning in the first place.

5.4. Permitting and the Principle of Public Participation

Most delays in transmission projects are caused during the permitting phase. This concerns projects, listed in the TYNDP as much as PCI. Around 30 % of the TYNDP 2014 and of the PCI 2015 have exceeded their planned timeframes. In around two third of the cases permit granting was indicated as the reason for delay (ACER 2017, 24). Even though the TEN-E regulation prescribed a maximum time period of three and a half years for the permitting process for PCI. The regulation on trans-European energy infrastructure aims at a fast and streamlined process, however one that still respects the principles of the Aarhus Convention and the Espoo Convention (Regulation (EU) No 347/2013, (30)-(31)).

The Aarhus Convention, to which the EU is a party, was adopted in 1998. The convention aims "to contribute to the protection of the right of every person of present and future generations to live in an environment adequate to his or her health and well-being, each Party shall guarantee the rights of access to information, public participation in decision-making, and access to justice in environmental matters" (UNECE 1998, Art: 1). The public shall enjoy the right of public participation and access to information on projects concerning the environment. Moreover, their concerns have to be considered by the public authorities in their decision process.

Public opposition to high voltage lines is contributing to difficulties in the process and can add to delays in the permitting process. People living close to planned transmission projects are often concerned about health and environmental issues and then antagonize the project. For instance in the case of the Salzburg line in Austria, from St. Peter to Tauern, public opposition has been involved in the process and caused difficulties during planning and permitting ('IG-Erdkabel' 2018). Major concerns were health issues, especially the relation between leukaemia and high voltage lines, even though no scientific prove has so far testified this correlation (Kölbel and Walter 2015). However, that causes worries and reluctance among the population and the principle of public participation provides a tool to be involved into the decision-making process.

The Espoo Convention on Environmental Impact assessment in a transboundary context obliges parties to the agreement to "either individually or jointly, take all appropriate and effective measures to prevent, reduce and control significant adverse transboundary environmental impact from proposed activities" (UNECE 1991, Art: 2). Environmental impact assessments are important and have to be conducted. For project promoters, however, they are complicated and time consuming studies. In the PCI list of 2015 several projects faced delays because of environmental problems (ACER 2017, Annex V).

Environmental impact assessments as well as the Aarhus Convention are of great significance to respect and guarantee the necessity of environmental protection and the principle of public participation. The TEN-E acknowledges the importance of these, but at the same time aims to find ways to prevent delays in the permitting phase. The PCI list of 2015 however has thus far not shown much more success in the permitting phase than projects on the TYNDP list. A reason, explaining this is that by 2016 not all PCI were yet in the new permitting process as outlined in the trans-European infrastructure regulation (ENTSO-e 2016a). Hence, there is still more potential to accelerate the process of permitting and prevent delays, once the TEN-E regulation is fully implemented in all member states.

6. Conclusion

The ENTSO-e’s network development plans are quite comprehensive and reflect the urgency of transmission capacity upgrades. Greenpeace even criticised the TYNDP 2012 for entailing more projects than necessary for integrating RES (Ackermann et al. 2014, 9). The problem of transmission shortages is not caused by a lack of identifying the necessity of infrastructure projects but rather by the implementation of infrastructure projects.

Four major drawbacks that hinder grid development were analysed. The bottom-up approach makes it difficult to push transmission line projects, necessary for a Union development, but instead favours national developments. Unbundling causes inefficient use of transmission capacity, and further regulation will be necessary to counteract in this regard. Permitting procedures, furthermore, add difficulties to the implementation phase. Nevertheless, they are rather only reason for delay, than for not building them in the first place. Uncertainty in the energy sector, however, and investment risks are the two major causes for hesitant network development and planning.

It has been demonstrated that there is not one single solution of how a European grid needs to look like by 2030. The only common basis is that cross-border connections are vital and that transfer capacity needs to be increased by a couple of hundred GW and transmission lines need to be extended by tens of thousands of km until 2030. However, where exactly electricity flows are expected, is difficult to determine, especially, when considering unknown variables like the extent of nuclear deployment in the power mix or the economic viability of CCS, or the power to gas technology.

The more certain and precise political strategies are on electricity generation and on consumption in the upcoming decades are, the better the development for transmission network infrastructure. If grid development is not keeping up with RES development curtailment will increase dramatically. The TYNDP 2018 estimated that around 160 TWh and more per year could be curtailed by 2040, if no additional electricity infrastructure is built after 2020 (ENTSO-e 2018a, 22). This amount represents more than twice the total Austrian electricity consumption in 2017 (E-Control 2017, 26).

If electricity from RES cannot make it to the grid, and CO_2 emitting thermal power station have to start up, because wind or solar energy do not make their way to consumer centres, than decarbonisation goals will not be met. Transmission network development may not be the first thing that comes into someone's mind when thinking about climate change mitigation. Nevertheless, it plays a crucial role and without sufficient network development, the energy transition is not feasible.

Bibliography:

ACER. 2017. 'Consolidated Report on the Progress of Electricity and Gas Projects of Common Interest for the Year 2016'. Ljubljana, Slovenia. http://www.acer.europa.eu/official_documents/acts_of_the_agency/publication/consolidated%20report%20on%20the%20progress%20of%20electricity%20and%20gas%20projects%20of%20common%20interest%20for%20the%20year%202016.pdf - accessed: 04.05.2018

Ackermann, Thomas, Eckehard Tröster, Phillipp Schierhorn, Sven Teske, and Tom Brown. 2014. 'Powe[R] 2030: A European Grid for 3/4 Renewable Electricity by 2030.' Alexandra Dawe (ed.). Greenpeace. Darmstadt, Germany. https://www.greenpeace.de/files/publications/201402-power-grid-report.pdf - accessed: 19.03.2018.

Bahar, Heymi, and Jehan Sauvage. 2013. 'Cross-Border Trade in Electricity and the Development of Renewables-Based Electric Power: Lessons from Europe'. In: *OECD Trade and Environment Working Papers* 2013 (02).

Berg Skånlund, Anders. 2013. 'Loop Flows-Final Advice. Prepared for the European Commission.' THEMA Consulting Group. Brussels, Belgium. https://ec.europa.eu/energy/sites/ener/files/documents/201310_loop-flows_study.pdf - accessed: 17.05.2018.

Boisseleau, Francois, and Martha Roggenkamp. 2005. 'The Liberalisation of the EU Electricity Market and the Role of Power Exchanges' In: Boisseleau, Francois and Roggenkamp, Martha (eds.): *The Regulation of Power Exchanges in Europe*. Oxford, United Kingdom: Intersentia.

Brauner, Günther. 2013. 'Die Bedeutung Flexibler Kraftwerke Für Die Energiewende.' In: *Elektrotechnik Und Informationstechnik* 130 (3): 87–92.

———. 2016. *Energiesysteme: regenerativ und dezentral: Strategien für die Energiewende*. Wiesbaden, Germany: Springer Fachmedien.

Bundesnetzagentur. 2014. 'Monitoring Report 2014'. Bonn, Germany. https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2014/Monitoringbericht_2014_BF.pdf?__blob=publicationFile&v=3 - accessed: 15. 04. 2018.

———. 2015. 'Monitoring Report 2015'. Bonn, Germany. https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/BNetzA/PressSection/ReportsPublications/2015/Monitoring_Report_2015_Korr.pdf?__blob=publicationFile&v=4 - accessed: 15. 04. 2018.

———. 2016. 'Monitoring Report 2016'. Bonn, Germany. https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/BNetzA/PressSection/ReportsPublications/2016/MonitoringReport_2016.pdf?__blob=publicationFile&v=3 -

accessed: 15. 04. 2018.

———. 2017. ‘Monitoring Report 2017 - Key Findings’. Bonn, Germany. https://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/Areas/ElectricityGas/CollectionCompanySpecificData/Monitoring/KernaussagenEng_MB2017.pdf?__blob=publicationFile&v=2 - accessed: 15. 04. 2018.

———. 2018a. ‘BBPlG, Vorhaben 5: Wolmirstedt – Isar (SuedOstLink)’. Netzausbau. Bonn, Germany. https://www.netzausbau.de/leitungsvorhaben/bbplg/05/de.html - accessed: 17. 05. 2018.

———. 2018b. ‘EEG in Zahlen 2016’. Bonn, Germany. https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/ErneuerbareEnergien/ZahlenDatenInformationen/EEGinZahlen_2016_BF.pdf;jsessionid=98C68A8A49642964B6C7A9FCC0A37CDD?__blob=publicationFile&v=3 - accessed: 18. 04. 2018.

COM (2011) 112 final. 2011.‘Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions: A Roadmap for Moving to a Competitive Low Carbon Economy in 2050.

COM (2011) 885 final. 2011. ‘Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions: Energy Roadmap 2050.

COM (2014) 15 final. 2014. ‘Communication from the Commission to the European Parliament, the Council, The European Social Committee and the Committee of the Regions: A Policy Framework for Climate and Energy in the Period from 2020 to 2030.

COM (2015) 82 final. 2015. Communication from the Commission to the European Parliament and the Council: Achieving the 10% Electricity Interconnection Target. Making Europe’s Electricity Grid Fit for 2020.

COM (2017) 718 final. 2017. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Communication on Strengthening Europe’s Energy Networks.

Commission Delegated Regulation (EU) 2018/540 of 23 November 2017 Amending Regulation (EU) No 347/2013 of the European Parliament and of the Council as Regards the Union List of Projects of Common Interest.

Commission Expert Group on Electricity Interconnection Targets. 2017. ‘Towards a Sustainable and Integrated Europe Report of the Commission Expert Group on Electricity Interconnection Targets’. Brussels, Belgium. https://ec.europa.eu/energy/sites/ener/files/documents/report_of_the_commission_expert_group_on_electricity_interconnection_targets.pdf - accessed: 30.04.2018.

Commission Regulation (EU) 2016/1388 of 17 August 2016 Establishing a Network Code on Demand Connection (Text with EEA Relevance).

Commission Regulation (EU) 2016/1447 of 26 August 2016 Establishing a Network Code on Requirements for Grid Connection of High Voltage Direct Current Systems and Direct Current-Connected Power Park Modules (Text with EEA Relevance).

Commission Regulation (EU) 2016/631 of 14 April 2016 Establishing a Network Code on Requirements for Grid Connection of Generators (Text with EEA Relevance).

Diermann, Ralph. 2018. 'Wüstenstrom Für Europa: Was Wurde Aus Desertec?' In: *Spiegel Online*. Hamburg, Germany. http://www.spiegel.de/wissenschaft/technik/desertec-was-wurde-aus-den-solarkraftwerken-in-nordafrika-a-1196664.html - accessed: 28.04.2018.

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC'. 2009. Official Journal of the European Union (Text with EEA Relevance).

Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 Concerning Common Rules for the Internal Market in Electricity and Repealing Directive 2003/54/EC (Text with EEA Relevance).

E-Control. 2018. 'Projects of Common Interest'. Vienna, Austria. https://www.e-control.at/marktteilnehmer/news/-/asset_publisher/wjmR2nwzCMOn/content/id/435151 - accessed: 9 May 2018.

———. 2017. 'Key Statistics 2017'. Vienna, Austria. https://www.e-control.at/documents/20903/443907/Statistikb17_E_fin-Ansicht.pdf/0b2b17b8-fab6-e20e-d432-44894021eefc - accessed: 26.05.2018.

Engel, Von Björn. 2018. 'Der irre Tanz um die Öko-Bilanz bei E-Autos'. https://www.welt.de/motor/article175010555/Oeko-Bilanzen-fuer-E-Autos-sind-fast-unmoeglich.html - accessed: 20.05.2018.

ENTSO-e. 2013. 'Definitons: Appendix 1 of System Operation Agreement'. Brussels, Belgium. https://docstore.entsoe.eu/Documents/Publications/SOC/Nordic/System_Operation_Agreement_appendices_English_2015_update.pdf - accessed: 27.04.2018.

———. 2014a. 'TYNDP 2014'. Brussels, Belgium. https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/141031%20TYNDP%202014%20Report_.pdf - accessed: 20.04.2018.

———. 2014b. 'TYNDP. Frequently Asked Questions'. Brussels, Belgium. https://docstore.entsoe.eu/Documents/TYNDP%20documents/1410131_TYNDP_FAQs.pdf - accessed: 29.04.2018.

———. 2015a. '2015 Monitoring Update of the TYNDP 2014 Table of Projects'. Brussels, Belgium. https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/TYND

P%202014%20monitoring%20update_statistics%20and%20table_FINAL.PDF - accessed: 04.05.2018.

———. 2015b. ‘TYNDP 2016 Scenario Development Report: Final after Public Consultation’. Brussels, Belgium. https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/rgips/TYNDP2016%20Scenario%20Development%20Report%20-%20Final.pdf - accessed: 23.04.2018.

———. 2016a. ‘Insight Report: A Push for Projects of Common Interest’. Brussels, Belgium. http://tyndp.entsoe.eu/2016/insight-reports/common-projects/ - accessed: 30.04.2018.

———. 2016b. ‘TYNDP 2016 Executive Report’. Brussels, Belgium. http://tyndp.entsoe.eu/exec-report/sections/ - accessed: 27.04.2018.

———. 2017a. ‘Annual Report 2016’. Brussels, Belgium. http://annualreport2016.entsoe.eu/wp-content/uploads/annual-report-2016-ENTSO-E.pdf - accessed: 21.04.2018.

———. 2017b. ‘Regional Investment Plan 2017 Regional Group Continental Central South’. Brussels, Belgium. https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP2018/rgip_CCS_Full.pdf - accessed: 27.04.2018.

———. 2018a. ‘European Power System 2040 Completing: The Map. The Ten-Year Network Development Plan 2018 System Needs Analysis’. Brussels, Belgium. https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP2018/european_power_system_2040.pdf - accessed: 22.05.2018.

———. 2018b. ‘How Do We Do It? Planning Studies’. Brussels, Belgium. https://www.entsoe.eu/publications/tyndp/#how-do-we-do-it-planning-studies - accessed: 14.05.2018.

———. Project List from TYNDP 2012, 2014 and 2016. Brussels, Belgium. http://tyndp.entsoe.eu/maps-data/ - accessed 27.04.2018.

European Commission. 2016. ‘Project of Common Interest: Südlink - The North-South German Interconnector’. Brussels, Belgium. https://ec.europa.eu/energy/sites/ener/files/documents/factsheet_de_n-s_interconnection_2017.pdf - accessed: 22.05.2018.

———. 2017. ‘CEF Energy Key Figures’. Brussels, Belgium. https://ec.europa.eu/inea/sites/inea/files/cef_energy_keyfigures_2017_leaflet_final_0.pdf - accessed: 05.05.2018.

———. 2018a. ‘CEF Energy - Innovation and Networks Executive Agency’. Innovation and Networks Executive Agency. Brussels, Belgium. https://ec.europa.eu/inea/en/connecting-europe-facility/cef-energy - accessed: 12.05.2018.

———. 2018b. ‘Energy Efficiency: Saving Energy-Saving Money’. Brussels, Belgium. https://ec.europa.eu/energy/en/topics/energy-efficiency - accessed: 28.04.2018.

European Environment Agency. 2017. ‘Overview of Electricity Production and Use in Europe’. https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment - accessed: 09.04.2018.

Eurostat. 2017. ‘Electricity and Heat Statistics - Statistics Explained’. http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_and_heat_statistics#Production_of_electricity - accessed: 30.04.2018.

———. 2018. ‘Supply, Transformation and Consumption of Electricity - Annual Data’. http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do - accessed: 25.04.2018.

Frankfurter Allgemeine. 2014. ‘Desertec am Ende: Der Traum vom Wüstenstrom ist gescheitert’, Frankfurt am Main, Germany. https://www.faz.net/1.3207437 - accessed: 28.04.2018.

Feldhaus, Peter, Daniel Fürstenwerth, Matthias Gohl, Bastian Schröter, and Thomas Vahlenkamp, 2010. ‘Transformation of Europe’s Power System until 2050: Including Specific Considerations for Germany.’ McKinsey&Company. Düsseldorf, Germany. https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/epng/pdfs/transformation_of_europes_power_system.ashx - accessed: 15.03. 2018.

Götz, Manuel, Jonathan Lefebvre, Friedemann Mörs, Amy McDaniel Koch, Frank Graf, Siegfried Bajohr, Rainer Reimert, and Thomas Kolb. 2016. ‘Renewable Power-to-Gas: A Technological and Economic Review’. In: *Renewable Energy* 85 (2016): 1371–90.

Haucap, Justus, and Beatrice Pagel. 2013. ‘Ausbau der Stromnetze im Rahmen der Energiewende: Effizienter Netzausbau und Struktur der Netznutzungsentgelte’. In: *List Forum für Wirtschafts- und Finanzpolitik* 39 (3): 235–53.

Horstmann, Theo. 2006. ‘Das europäische Verbundnetz der Union for the Co-ordination of Transmission of Electricity (UCTE) – Entstehung-Erfolgsgeschichte-Herausforderungen’. In: Horst A. Wessel (ed.): *Von der Leitung zum Netz: zur Entstehung und Zuverlässigkeit von Netzen für Energie und Kommunikation*. Berlin; Deutschland: VDE Verlag.

‘IG-Erdkabel’. 2018. Eugendorf, Austria. http://www.ig-erdkabel.at/ - accessed: 28.04.2018.

Kästner, Thomas, and Andreas Kießling. 2016. *Energiewende in 60 Minuten*. Wiesbaden, Germany: Springer Fachmedien.

Kölbel, Ralf and Maren Walter. 2015. ‘Gefährlicher Strom?: Hochspannungsleitungen und Gesundheit.’ In: SWR2. Stuttgart, Germany.

https://www.swr.de/swr2/wissen/gefaehrlicher-strom-hochspannungsleitungen-und-gesundheit/-/id=661224/did=16373106/nid=661224/b8s5iq/index.html - accessed: 23.05.2018.

Leeson, D., N. Mac Dowell, N. Shah, C. Petit, and P. S. Fennell. 2017. 'A Techno-Economic Analysis and Systematic Review of Carbon Capture and Storage (CCS) Applied to the Iron and Steel, Cement, Oil Refining and Pulp and Paper Industries, as Well as Other High Purity Sources'. In: *International Journal of Greenhouse Gas Control* 61 (2017): 71–84.

'Madrid Declaration': Energy Interconnections Links Summit Spain-France-Portugal-European Commission-EIB'. 2015. https://ec.europa.eu/energy/en/content/madrid-declaration - accessed: 30. 04. 2018.

Oberthür, Sebastian, and Claire Dupont. 2015.'Decarbonisation in the EU: Setting the Scene'. In: Sebastian Oberthür and Claire Dupont (eds.): *Decarbonization in the European Union: Internal Policies and External Strategies*. Hampshire, United Kingdom: Palgrave Macmillan.

Österreichs Energie. n.d. 'Daten und Fakten zum Stromnetz'. Vienna, Austria https://oesterreichsenergie.at/daten-fakten-zum-stromnetz.html - accessed: 24.04.2018.

Panos, Konstantin. 2013. *Praxisbuch Energiewirtschaft: Energieumwandlung, -Transport Und -Beschaffung Im Liberalisierten Markt*. 3rd ed. Berlin Heidelberg, Deutschland: Springer Vieweg.

Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009 on Conditions for Access to the Network for Cross-Border Exchanges in Electricity and Repealing Regulation (EC) No 1228/2003 (Text with EEA Relevance).

Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on Guidelines for Trans-European Energy Infrastructure and Repealing Decision No 1364/2006/EC and Amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009 (Text with EEA Relevance).

Regulation (EU) No 347/2013 Annex C (2015) 8052 final to amending Regulation (EU) No347/2103 of the European Parliament and of the Council as regards the Union list of projects of common interest.

Regulation (EU) No 1316/2013 of the European Parliament and of the Council of 11 December 2013 Establishing the Connecting Europe Facility, Amending Regulation (EU) No 913/2010 and Repealing Regulations (EC) No 680/2007 and (EC) No 67/2010 (Text with EEA relevance).

Roadmap 2050 (ed.) 2011. 'Power Perspectives 2030: On the Road to a Decarbonised Power Sector'. Den Haag, The Netherlands. http://www.roadmap2050.eu/attachments/files/PowerPerspectives2030_FullReport.pdf - accessed: 30.03.2018.

Sattich, Thomas. 2015. 'Electricity Grids: No Decarbonisation without Infrastructure'.

In: Sebastian Oberthür and Claire Dupont (eds.): *Decarbonization in the European Union: Internal Policies and External Strategies*. Hampshire, United Kingdom: Palgrave Macmillan.

Sokołowski, Maciej. 2016. *Regulation in the European Electricity Sector*. London, United Kingdom: Routledge.

Statista. 2018. 'Pkw-Bestand - Europäische Länder 2015 | Statistik'. Hamburg, Germany. https://de.statista.com/statistik/daten/studie/163405/umfrage/pkw-bestand-in-ausgewaehlten-europaeischen-laendern/ - accessed: 27.04.2018.

TEU. 2012.'Consolidated Version of the Treaty on the European Union'. C 326/13. https://eur-lex.europa.eu/resource.html?uri=cellar:2bf140bf-a3f8-4ab2-b506-fd71826e6da6.0023.02/DOC_1&format=PDF - accessed: 09.05.2018.

Teske, Sven, Steve Sawyer, and Oliver Schäfer. 2015. 'Greenpeace. Energy [r]Evolution: A Sustainable World Energy Outlook 2015'. Hamburg, Germany. http://www.greenpeace.org/archive-international/Global/international/publications/climate/2015/Energy-Revolution-2015-Full.pdf - accessed: 02.05.2018.

TFEU. 2012.'Consolidated Version of the Treaty on the Functioning of the European Union'. C 326/47. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:12012E/TXT&from=EN - accessed: 09.05.2018.

Umweltbundesamt. 2018.'Carbon Capture and Storage'. Dessau-Roßlau, Germany. http://www.umweltbundesamt.de/themen/wasser/gewaesser/grundwasser/nutzung-belastungen/carbon-capture-storage - accessed: 14.05. 2018.

UNECE. 1991. 'Convention on Environmental Impact Assessment in a Transboundary Context'. Espoo, Finland. https://www.unece.org/env/eia/eia.html - accessed 06.05.2018.

———. 1998. 'Convention on Access to Information, Public, Participation in Decision-Making and Access to Justice in Environmental Matters'. Aarhus, Denmark. http://www.unece.org/env/pp/treatytext.html - accessed: 06.05.2018.

UNFCCC. 2015. 'Paris Agreement'. Paris, France. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement - accessed: 24.05.2018.

Würfel, Philip. 2017. *Unter Strom: Die neuen Spielregeln der Stromwirtschaft*. Wiesbaden, Deutschland: Springer Fachmedien.

List of figures