Germany's Wind and Solar Deployment 1991-2015

Facts and Lessons Learnt

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ABSTRACT

In this case study, Germany´s wind and solar deployment from 1991 to 2015 is analyzed with wind and solar representing a major pillar in Germany´s energy transition. Germany´s NREAP capacity goals for wind and solar power have been outreached, amongst others due to the (at times) generous and investor-risk minimizing feed-in tariff system (EEG) as well as supportive grid connection conditions for renewable energy generators. For a successful integration of further amounts of wind and solar energy, system flexibility, amongst others via a stronger integration of the European electricity market, is key. Also, market design adjustments will become necessary, for which the two in this research cooperation with Stanford University analyzed electricity markets in California and Texas can represent best-practice examples with regard to short-term gate closure times and regionalized electricity pricing.

Keywords: Comparative analysis, Decarbonization, RES deployment, Energy sector regulation

JEL classification: Q42, Q48, L94, N70

PROJECT DESCRIPTION & ACKNOWLEDGEMENTS

Germany as well as the U.S. states of California and Texas have enacted policies and implemented programs to incentivize the expansion of renewable generation in electricity systems. Each of these markets vary with respect to the capacity installed, the costs to ratepayers and the impacts on incumbent utilities and conventional generators. Germany, California and Texas provide important – and in some aspects contrasting – examples of how policies can be put into effect as well as the potential of renewable deployment and the impact of increased renewable penetration on the market.

Within this research project, the expansion of renewables in Germany, California and Texas is analyzed to identify similarities and differences in policy structures as well as the penetration of variable renewable resources. In doing so, the state of renewable energy in Germany, California and Texas is examined via three independent case studies. Two additional studies compare the differences and similarities between these three markets.[1]

The case study at hand is a meta-study about the German deployment of renewable energy, particularly solar and wind.

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[1] The comparative study on Germany, California and Texas was published by EWI [1]. The other comparative study on Germany, California and Texas was published by Steyer-Taylor Center for Energy Policy and Finance, Stanford University: https://law.stanford.edu/publications/a-tale-of-three-markets/

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ABBREVIATIONS

BDEW	Federal Association of Energy and Water Industry ("Bundesverband der Energie- und Wasserwirtschaft")
BMWi	Federal Ministry for Economic Affairs & Energy ("Bundesministerium für Wirtschaft und Energie")
BNetzA	Federal Network Agency ("Bundesnetzagentur")
CHP	Combined heat and power
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DEHSt	German Emissions Trading Authority ("Deutsche Emissionshandelstelle")
Destatis	Federal Statistical Office
DSO	Distribution system operator
EEG	Renewable Energy Source Act ("Erneuerbare-Energien-Gesetz")
EEX	European Energy Exchange
EIA	U.S. Energy Information Administration
EnLAG	Power Grid Expansion Act
ENTSO-E	European Network of Transmission System Operators for Electricity
EPEX SPOT	European Power Exchange
EU	European Union
EU-ETS	European Union Emissions Trading System
EUR	Euros
FIT	Feed-in tariff
gCO_2	Gram of carbon dioxide
GDP	Gross domestic product
GHI	Global horizontal irradiance
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt-hour
km	Kilometer
km^2	Square kilometer

kV	Kilovolt
kWh	Kilowatt-hour
LCOE	Levelized cost of energy
m/s	Meters per second
m^2	Square meter
Mio	Million
MW	Megawatt
MWh	Megawatt-hour
NREAP	National Renewable Energy Action Plan
NREL	U.S. National Renewable Energy Laboratory
OECD	Organisation for Economic Co-operation and Development
OTC	Over-the-counter
PV	Photovoltaics
RE	Renewable energy
SAIDI	System Average Interruption Duration Index
tCO_2	Ton of carbon dioxide
TSO	Transmission system operator
TWh	Terawatt-hour
TYNDP	Ten Year Network Development Plan
UBA	Federal Environment Agency ("Umweltbundesamt")
V	Volt
VAT	Value-added tax
VRE	Variable renewable energy

1 INTRODUCTION

National Policy Backdrop

Germany has taken a fundamental policy decision to move toward a mostly renewables-based sustainable energy system in the long term. The foundations for this strategy were laid in the early 1990s with the first law supporting the feed-in of electricity generated from Renewable Energy ("RE") sources. In 2000, the German government significantly extended this support scheme with the adoption of the Renewable Energy Source Act ("Erneuerbare-Energien-Gesetz" or "EEG") 2000, a technology-specific feed-in tariff scheme ("FIT"). Also, it agreed on a phase-out schedule with the owner-operators of German nuclear power plants.

Based on these foundations, the German government laid out the Energy Concept in 2010, and the Energy Package in 2011. The Energy Concept 2010 establishes the principles of a long-term, integrated energy pathway through 2050. The main components of this concept include a general de-carbonization through an 80% Greenhouse gas (GHG) emissions reduction by 2050 with respect to 1990 levels, and an 80% RE share in the electricity sector by 2050. At the same time a "high level of security of supply and economic competitiveness" should be guaranteed, however without any quantitative definition of a goal. The Energy Concept 2010 also changed the 2001 nuclear phase-out law, prolonging the lifetime of existing German nuclear power plants by eight to fourteen years.

Following the Fukushima Daiichi nuclear disaster in March 2011, however, a political decision was made to accelerate the nuclear phase-out by the end of 2022, starting with the immediate closure of the eight nuclear plants with the highest estimated risk of failure [2]. This decision enjoyed extensive public support, building on an anti-nuclear movement tradition dating back to the early 1970s. This decision had a major impact on German energy policy and resulted in the adoption of the 2011 Energy Package, a set of measures to accelerate the so-called energy transition ("Energiewende"), including revised rules for supporting RE, improving energy efficiency, accelerating grid expansion, and for the creation of a new energy- and climate fund [3].

The German "Energiewende" describes this long-term energy transition towards a sustainable energy supply which is mainly based on the Energy Concept 2010 and the Energy Package 2011. The EEG is the main policy instrument adopted to reach the transition of the electricity sector. Since its adoption in 2000, it comprises a fixed feed-in tariff scheme based on an earlier FIT scheme established in 1991. Additionally, since 2012, the EEG includes a market premium scheme.[2] Besides the electricity sector, the "Energiewende" also comprises a transition in the heat and transportation sectors.

Area and Population

Germany is the fourth-largest country in the European Union ("EU") by area and shares borders with nine countries (Table 1). It has a largely temperate and marine climate, with its terrain a mix of lowlands in the north along with highlands in the center, the Bavarian Alps in the south, and a coastline

[2] The market premium scheme is expected to become more and more important.

along the Baltic and Nordic Seas. Germany is Europe´s leading economy in terms of gross domestic product ("GDP") and a leading exporter of machinery, vehicles, chemicals, and household appliances.

Area [km^2]	357´340
Inhabitants 2013	80´767´000
Inhabitants / km^2	226
GDP 2014 [Bn EUR]	2´903.8

Table 1, data provided by DESTATIS [4]

The energy intensity of its economy, its high population density, its location in the heart of Europe´s energy system, and its ambitious vision to become a world leader in RE deployment and energy efficiency make the "Energiewende" a demanding undertaking with the overall goal of maintaining a balance between sustainability, affordability, and competitiveness [2].

The following case study is a meta-study aimed at describing the German experience in deploying renewable energy, particularly solar and wind. The literature used to compose this report is mostly based on official statistics, academic literature and publicly available reports and studies. Original analysis is mostly confined to the in-depth literature review, compilation and presentation of data, and, in particular, the comparative parts of this report. Also, the analysis is mainly based on qualitative assessments. Quantitative results were included and cited where beneficial to the overall scope of the project. However, an in-depth quantitative analysis e.g. based on EWI´s computational modeling competences was not intended and would have been beyond the scope of this work.

2 STATUS QUO & HISTORY

2.1 Market Structure Fundamentals

Electricity Market

The German electricity market consists of five main business models: Electricity generation, transmission grid operation (extra high voltage electricity transmission), distribution grid operation (high to low-voltage distribution), wholesale trading of electricity, and retail of electricity. The transmission grid and generation are unbundled.[3] This market structure is a consequence of the electricity market liberalization that followed directive 96/92/EC concerning common rules for the internal market in electricity by the European Commission (1996) [5]. For historic reasons, however, many companies – the former integrated utilities – still comprise several of these businesses.[4]

Generators own and operate the power plants for electricity generation. The German electricity grid is operated by four Transmission System Operators ("TSOs") and over 800 Distribution System Operators ("DSOs") [6]. The role of the TSOs comprises investment and operation of the grid as well as grid stabilization using measures such as balancing power activation, re-dispatch measures, curtailment of variable renewable energy ("VRE"), grid loss compensation, reactive power compensation, and black start ability [7]. Utilities are responsible for the retail sale of electricity to end consumers.[5]

Germany has very few independent power producers. Instead, integrated companies that are also active in the retail business, either directly or via subsidiaries, own most conventional power plants. Examples of such integrated companies include EON, RWE, EnBW and Vattenfall, but also smaller companies and municipal utilities. Germany, in line with the EU, has opted for retail competition even in the residential sector. This means that residential customers have the option to switch suppliers. In turn, retail prices, even for residential consumers, are not regulated. Although changing an electricity provider is relatively easy, the rate of consumers switching providers is modest. In 2013, most residential customers still bought electricity from the local incumbent utility (79%) of whom a large part still buys electricity at base contracts[6] (34%) while some have switched to contracts other than the base contract from the same local utility (45%) [8]. About 21% of residential customers switched to suppliers other than the local incumbent utility.

There is only one bidding zone[7] for Germany and Austria, which often features identical prices with neighboring markets such as Switzerland or France. However, there increasingly exist internal grid

[3] The legal requirement is "legal unbundling". Three out of four TSOs have adopted the more strict "ownership unbundling" by selling their transmission grids, the exception being the TSO EnBW. Many distribution system operators, in particular small ones, are still fully vertically integrated with local utilities.

[4] For example, E.ON, Germany's largest energy company, has announced only in December 2014 its plans to split up into two new companies, one of them comprising renewable/distribution/retail businesses, and the other one comprising conventional generation and wholesale.

[5] Re-dispatch describes the short-term changes in the dispatch on order by the TSOs to address congestions

[6] Even though the base tariff was higher.

[7] A bidding zone is the largest geographical area within which market participants in the electricity market are able to exchange energy without any constraints. In other words, it is assumed that there are no major congestions [9].

bottlenecks in Germany, especially between the North-East and the South-West (see Section 2.3). These congestions are not transparent to the market participants and thus not included in their economic decisions. Rather, they are managed with non-market interventions by the TSOs.[8]

Wholesale electricity trading takes place via the electricity exchanges (i.e. European Energy Exchange ("EEX"), European Power Exchange ("EPEX SPOT")) and via off-exchange/over-the-counter ("OTC") trading. The largest part of the financial electricity trade volume is made as OTC trades (around 93%), whereas around 7% is traded on the electricity exchanges [6]. OTC trades are accomplished in direct bilateral agreements or on broker platforms. Electricity trades on electricity exchanges take place at EEX (Leipzig) for derivatives trades, and at EPEX SPOT (Paris, Leipzig) for spot trades and yield important price signals also for the OTC trade. On the derivatives exchange EEX, power contracts with terms ranging from weeks to years with a lead time ranging from one week to around four years in the future are traded [6]. On the spot exchange EPEX SPOT, short-term contracts (for physical delivery of electricity) are traded.[9]

On the day-ahead market of EPEX SPOT, the order book for the individual 24 hours of the respective day is open up to forty-five days before delivery day, and closes at 12 PM for the daily auction. Thus, the minimum time to delivery is 12 hours. There are minimum and maximum bid limits of - 500 and + 3000 EUR. After the day-ahead market auction for hourly products a second auction takes place at 3 PM for quarter-hourly products. This auction is name intraday-auction. On the intraday market of EPEX SPOT, there is a continuous trading of the hourly contracts starting at 3 PM and of the 15-minute contracts starting at 4 PM, with a closing time of 30 minutes before delivery [6]. Day-ahead markets are coupled with most of the other European electricity markets; thus, market prices are determined simultaneously taking into account potential physical bottlenecks among the markets.

The dispatch is the planned schedule for the power plant utilization by the power plant operator. The result of the dispatch is the spatial and timely allocation of power plant usage. The power plant operator has to announce the timetable for power plant utilization to the TSO of his control area at 2:30 PM on the day before the delivery day. The sum of the schedules of all four control areas leads to the German dispatch for the next day – the planned schedule for all German power plants. If network congestions occur, re-dispatch measures are applied by the TSOs [6][10].

Forecast and Balancing

To help balancing electricity supply and demand in the system, in each TSO´s control zone so-called balance groups ("Bilanzkreise") are requested to keep electricity inflows and outflows within the group in balance for every quarter hour. Balance groups are bookkeeping energy accounts to equate physical electricity generation and consumption within the balance group, as well as financial electricity trade among balance groups. Any forecasted quarter hour imbalances within the balance group are reported to the TSO one day in advance. Electricity from RE generators within the FIT scheme of the Renewable Energy Source Act ("EEG") is grouped in special RE balance groups managed by the TSOs themselves.

[8] Such non-market interventions comprise a forced re-dispatch of generators, deviating from market results, and a support scheme to reward generators which are needed for re-dispatch purposes but cannot recover their fixed cost in the single bidding zone.
[9] The day-ahead market is "sufficiently" liquid and hence this market is often used as the reference market in electricity market analyses.

Thus, forecasting and balancing of the portion of RE generation under the FIT scheme is done by the TSO that manages the respective special RE balance group. The TSOs then check the plausibility of these reports when calculating their schedule management. Up to one hour before delivery, the balance groups can correct their balance via electricity trades with other balance groups and report their updated forecasts to their respective TSO. The TSOs then check for imbalances of the sum of all balance groups and activate, if needed, balancing power to re-establish total system balance. The costs arising to the TSO due to the balancing power capacity provision are passed through to the consumers, and the costs for the actual electricity generated by the balancing power plants to keep system balance is to be paid by the balance groups proportionately to their level of imbalance, creating an incentive for the balance groups to improve forecasts [6].

If the individual imbalances lead to an aggregate imbalance, the TSO will balance it by activating positive or negative physical power (i.e., an increase or decrease of generation or load). Depending on the time frame, this is done in one of the following three physical markets:

1. Primary reserve balancing market (activation time: 30 seconds; minimum capacity bid: 1 MW)
2. Secondary reserve balancing market (activation time: 5 minutes; minimum capacity bid: 5 MW)
3. Tertiary/Minute reserve balancing power market (activation time: 15 minutes; minimum capacity bid: 5 MW)

Balancing power is procured in auctions. The four TSOs tender balancing power as pay-as-bid auctions on a common platform, with weekly auction periods for primary and secondary reserves and daily auctions for tertiary reserves. Bids in the secondary and tertiary reserve balancing market include capacity and energy price components. They are accepted based on the capacity price only. Activation of balancing power follows the energy price merit-order of the accepted bids. Generators eligible for bidding into the balancing power markets are subject to certain pre-qualification [11].

Institutions

The primary responsibility for energy policy rests with the Federal Ministry for Economic Affairs and Energy (“Bundesministerium für Wirtschaft und Energie,” or “BMWi”). Since December 2013, the responsibility for the Renewable Energy Source Act (“Erneuerbaren-Energien-Gesetz,” or “EEG”) also lies with the BMWi. The Federal Network Agency (“Bundesnetzagentur,” or “BNetzA”) is the sector-specific regulator, responsible for regulated network access and establishing and protecting competition in the sector. It also develops regular market monitoring reports. It increasingly takes on additional responsibilities for implementing energy policy of the Energiewende, particularly in the context of high voltage grid extensions. The core tasks of competition policy – control of abuse of market dominance, cartelization, and merger control – rest with the Federal Cartel Office (“Bundeskartellamt”), the national competition authority, and the federal states´ competition agencies. In important cases for the integrated European market, the European Commission (“DG Competition”) takes over for the national competition authorities. Finally, the German Emissions Trading Authority (“Deutsche Emissionshandelstelle,” or “DEHSt”) within the Federal Environment Agency (“Umweltbundesamt,” or “UBA”) is responsible for the administration of emissions trading [2].

2.2 RE Policy Design & Goal Achievement

RE Policy Design: Status Quo & History

The Renewable Energy Source Act ("Erneuerbaren-Energien-Gesetz," or "EEG") is the key support instrument for RE generators in Germany. RE generators can choose to market their electricity either themselves outside the EEG on the electricity exchanges or via qualification for assistance under the EEG. The EEG offers two options: Option one is a fixed FIT[10] scheme with a time-span of 20 years. The RE generators are granted a technology-specific fixed FIT for every kWh generated, which is then sold on the day-ahead market EPEX SPOT by the TSOs (Table 2). Therefore, under the FIT, investors are not subject to a price risk (e.g. from market risk or from correlation between RE investments).

Under the second option, the so-called "market premium scheme", generators themselves are responsible for selling their electricity on the market. However, they are entitled to a market premium (i.e., a bonus) in addition to their revenue earned on the market. The market premium is calculated as the difference between the technology-specific FIT and the technology-specific monthly market value (see Section 3.2). In addition, the market premium includes a management premium. This scheme is meant for RE generators to become accustomed to wholesale market participation.[11] RE generators are incentivized to reach a market value higher than the average market value. In the case of negative prices, RE generators under the market premium scheme still have an incentive to generate as long as the sum of the negative market price plus the market premium is still positive [14].[12]

EEG Feed-in Tariffs [cents EUR_{2014}/kWh]	
Hydro	3.33-12.45
Biomass	5.76-24.61
Geothermal	25.00-30.00
Wind onshore	8.66-9.62
Wind offshore	15.00-19.00
Photovoltaics	9.47-13.68

Table 2, data provided by BDEW [13]

RE generators are granted priority dispatch and are entitled to grid connection at the earliest possible moment. Grid connection costs are split among RE generators and grid operators. The generator pays for the connection to the closest grid connection point of the corresponding voltage level, whereas the grid operator – and, ultimately, all network user – pays for possible reinforcement measures necessary to grant this grid connection [14].

The EEG surcharge, equal to the sum of FITs and market premiums paid to RE generators minus the revenue from sales of that electricity, is added to the electricity bills of consumers. However, specific energy-intensive consumers are granted various reductions of the EEG surcharge and other levies, allowing a categorization of consumers into so-called "privileged and non-privileged electricity consumers" [2][14] (Section 2.6).

[10] The levels of the single FITs are the result of a political process, based on the specific electricity generation cost of the respective technology [12].
[11] It is expected that in the years to come the majority of new RE installations will fall under the market premium scheme.
[12] From 2016 onward, RE generators both under the FIT and market premium scheme do not receive any support for hours when market prices have been negative for more than 6 hours in a row and/or for wind generators if the rated power is larger than 3 MW [14].

The EEG has been subject to various amendments, with the last version being enacted in August 2014. RE promotion in Germany started in 1989 with the adoption of the "100/250 MW Wind Program," and the "1000 Roofs Program" in 1991. These combined with the Electricity Feed-In Act ("Stromeinspeisegesetz") in 1991, which was the first feed-in law to be introduced in Germany [15].

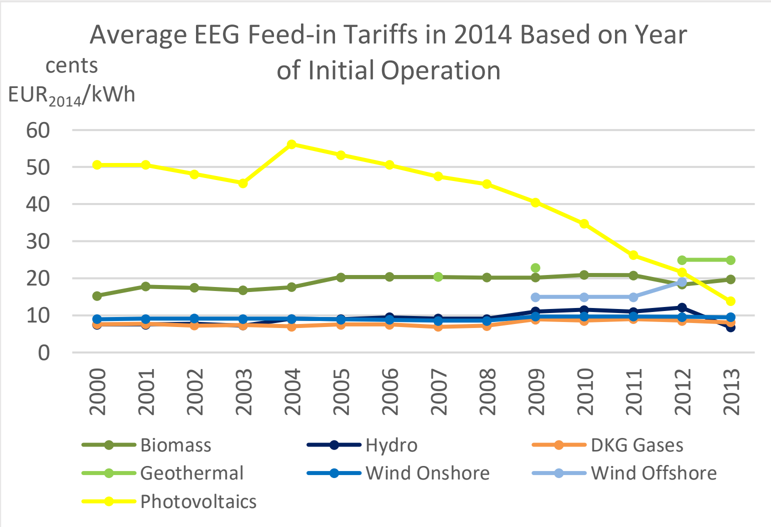

Figure 1, Source: EWI, data provided by BDEW [16]

The newly developed Renewable Energy Sources Act ("Erneuerbare Energien Gesetz", the "EEG") came into effect in 2000 and outlined the incentive structure to achieve the newly set target of a 12.5% share of RE generation of domestic demand by 2010. Generators were guaranteed preferential grid access and new FITs were set based on the estimated generation costs of RE systems, depending on technology, location, and project size and type, along with static technology-specific degressions [17]. A new version of the EEG was adopted in 2004, which added a 20% RE target for 2020 and modified several details from the 2000 version, including reduced EEG apportionment for energy-intensive industries, removal of the installed capacity limit, and decreased FITs for wind energy [18]. In the following years, the production costs for Photovoltaics ("PV") modules and module prices had decreased much faster than the FIT, resulting in larger profits for PV producers [19] (Figure 1). In the 2009 version of the EEG, rules for feed-in management measures, including compensation payments for curtailed energy, were added and the RE goal for 2020 was increased to 30% of domestic demand. Also, amongst other amendments, the static degression of 5% for PV, set in 2000, was redesigned to be a dynamic degression that depended on the installed capacity of PV in the previous year [20]. In 2012, a new version of the EEG was adopted, which introduced the market premium scheme open to all RE technologies and set a faster remuneration degression plan for PV. Moreover, a cap on PV support was set, allowing the FIT to continue as long as the total cumulative PV capacity did not exceed 52 GW and the 2020 RE goal was increased to 35% of domestic demand to be covered by RE generation [21][19].

Goal achievement

In 2007, the EU made a unilateral commitment to reduce its GHG emissions to 20% below 1990 levels. This commitment, together with a 20% RE target for the EU by 2020, was translated into EU legislation through the "Climate and Energy Package," which was adopted by European Council and Parliament at the end of 2008. In accordance with Article 4 of the Directive 2009/28/EC on the Promotion of the Use of Energy from Renewable Sources by the European Commission, Germany, like all other EU member states, prepared a so-called National Renewable Energy Action Plan ("NREAP") in 2010, which specifies Germany's expected contribution in terms of annual RE expansion to the EU's 20% RE goal by

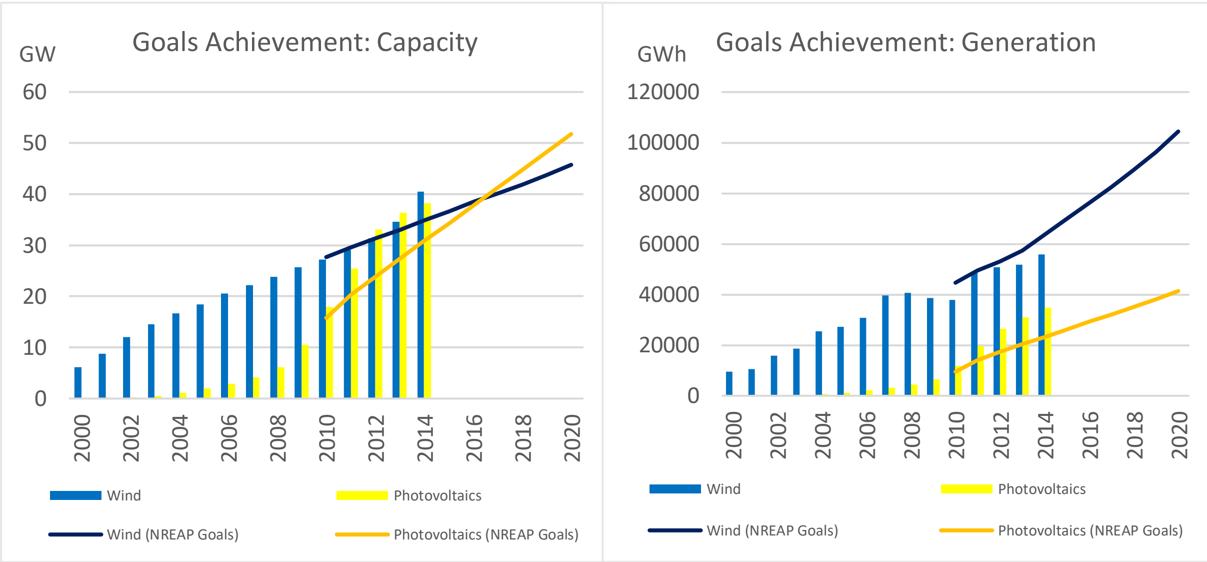

Figure 2, Source: EWI, data provided by BMWi [22]

2020 [23]. Wind capacity deployment between 2010 and 2014 overachieved the goals stated in the NREAP, reaching a capacity of 40.5 GW at the end of 2014 compared to the NREAP planned capacity target of 33.0 GW [24][23] (Figure 2). The goal for PV capacity deployment was strongly outperformed between 2010–2014, reaching an installed PV capacity of 38.2 GW by the end of 2014 compared to the NREAP goal of 27.3 GW [25][23]. Wind generation goals from the NREAP were underachieved in the years 2010–2014, and to a lesser extent in 2011 and 20 12. The strong deployment of PV capacity from 2010–2014 resulted in a generation of 35 TWh in 2014, which is an outperformance of the expected generation of 20.3 TWh [26][23].

Concerning national renewable energy targets, both the 2010 Energy Concept and the 2011 Energy Package introduced legislative restrictions in order to reach certain milestone targets for 2020, 2030, 2040, and 2050 with respect to GHG emission reduction and RE shares with respect to gross electricity consumption [3][28]. The documents state that by 2050, national GHG emissions are to be reduced by 80% compared to 1990 levels, and renewable energy generation is planned to account for 80% of national gross electricity consumption by 2050 [2] (Figure 3). These targets were designed in accordance with the NREAP goals [23].

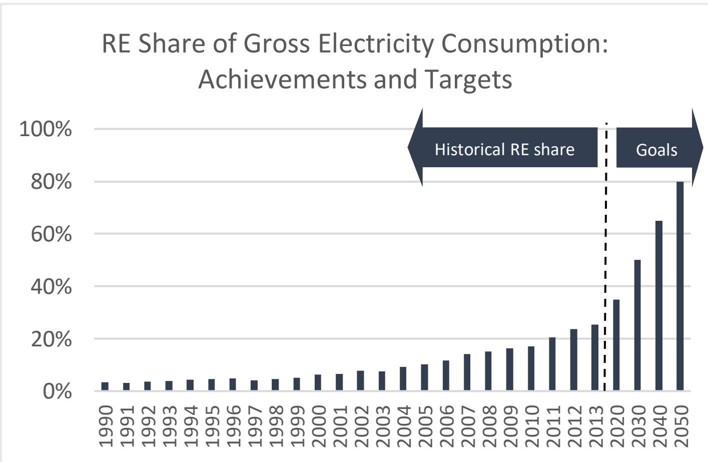

Figure 3, Source: EWI, data provided by BMWi [27]

2.3 Generation Mix

Capacity

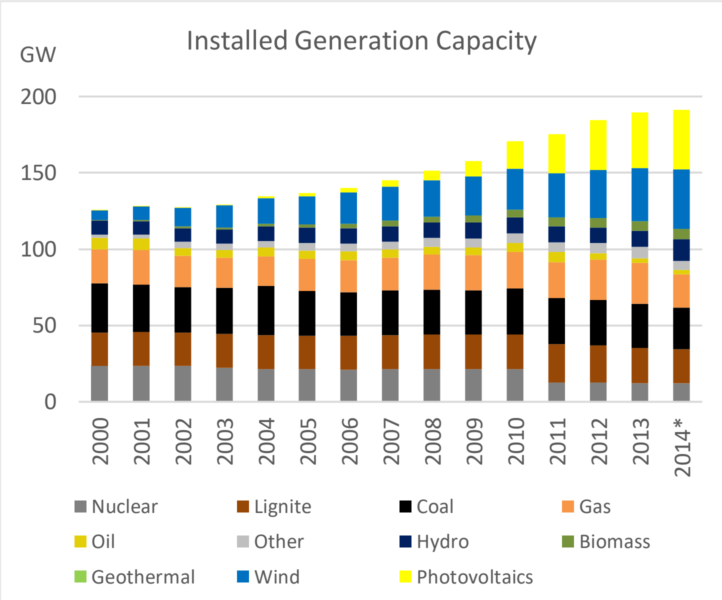

Figure 4, (*): estimated, Source: EWI, data provided by BNetzA [29] and BMWi [22]

In 2013, Germany had a total installed generation capacity of 189 GW, of which 34.7 GW was wind (33.8 GW onshore, 0.9 GW offshore) and 36.3 GW was PV (Figure 4).[13] Other RE installed capacity included 10.3 GW hydro, 6.5 GW biomass, and 0.02 GW geothermal. The installed conventional capacity consisted of 12.1 GW nuclear, 23.1 GW lignite, 29.2 GW coal, 26.7 GW natural gas, 2.9 GW oil, and 7.6 GW other capacity. In the wake of the nuclear disaster of Fukushima Daiichi in March 2011, the government decided to phase out nuclear electricity generation, with some 8.4 GW of nuclear generation capacity to be immediately shut down and a planned stepwise phase-out of the total pre-Fukushima nuclear capacity of 20.5 GW by 2022.

Around 68% of all PV capacity are rooftop systems with an installed capacity of less than 1 MW, while 32% of capacity consists of larger, ground-mounted PV plants and some rooftop plants with a capacity greater than 1 MW [30]. For wind, 46% of total wind capacity is built with 1–2 MW turbines, 32% with 2–3 MW turbines, 13% with turbines greater than 3 MW, and 9% with turbines less than 1 MW [31].

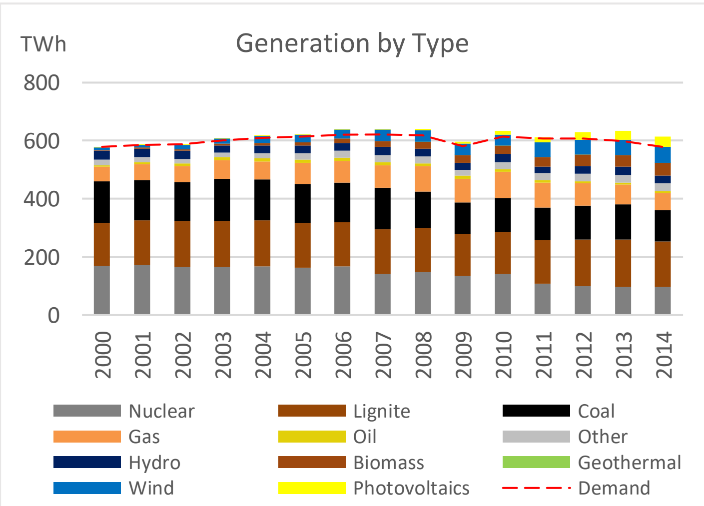

Figure 5, Source: EWI, data provided by BMWi [22]

Generation

Total electricity generation was at 614 TWh in 2014, with 16% of generation produced by nuclear (97 TWh), 25% by lignite (156 TWh), 18% by coal (109 TWh), and 9% by natural gas (58 TWh) (Figure 5). Oil and other conventional

[13] Official gross capacity data for 2014 are not yet available. The gross capacity data for 2014 displayed in the figure were estimated based on net capacity data published by BNetzA [29].

generators contributed 5% (34 TWh). In terms of renewable generation, generation of both wind and PV have seen strong growth in Germany since 2000. Wind generation has increased from 9.5 TWh in 2000 to 56 TWh in 2014 (55 TWh onshore, 1 TWh offshore), providing 9.1% of total generation. PV reached 35 TWh in 2014, compared to 0.06 TWh in 2000, equaling 5.7% of the total generation. Hydro accounted for 4.3 % and Biomass for 7% of total generation. RE generation accounted for 26% of the total generation in 2014.

Demand

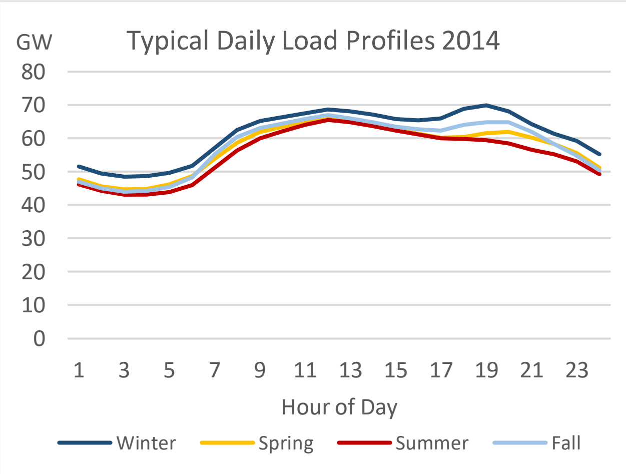

Figure 6, Source: EWI, data provided by ENTSO-E [32]

In 2014, gross domestic electricity demand[14] in Germany equaled 578.5 TWh (Figure 5 above) with imports of 38.9 TWh and exports of 74.6 TWh. In 2000, demand stood at 579 TWh and reached a peak of 621 TWh in 2007. In the wake of the financial crisis, demand dropped to 581 TWh in 2009. Yearly peak electricity demand typically occurs in the winter months between November and February, when the temperature is low and daylight-time is shorter. In spring, summer, and autumn, typical daily load profiles peak around noon, but in winter months, the peak is typically shifted between 6 and 7:30 PM (Figure 6).[15] In recent years, peak load excluding consumption of pumped storage and generating auxiliaries (i.e. net peak load, which accounts to around 91% of gross peak load) ranged from 73–80 GW [33]. Gross peak load ranged from 80-88 GW.[16]

Grid Structure

Transmission voltage (220-380 kV)	34´979 km
High voltage (110 kV)	96´308 km
Medium voltage (10-30 kV)	509´866 km
Low voltage (230/400 V)	1´156´785 km
Total	1´797´938 km

Table 3, Source: EWI, data provided by BNetzA [8]

In Europe, the grid is run at a frequency of 50Hz. In Germany, low voltage lines (230/400V) make up the majority of the grid length, followed by medium (10-30kV), high (110kV), and transmission voltage (220-380kV).

A total of approximately 1.79 million kilometers of electricity network (transmission and distribution) exists in Germany (Table 3).

[14] Gross electricity demand is defined as total generation plus imports minus exports.
[15] Load including network losses but excluding consumption of pumped storage and generating auxiliaries.
[16] Gross peak load includes network losses, consumption of pumped storage and generating auxiliaries.

A measure of grid reliability is the System Average Interruption Duration Index ("SAIDI")[17], which gives the average supply interruption time in the low and medium voltage grid for final consumers. Compared to other countries, the German grid infrastructure offers a relatively high reliability standard with an average interruption time of 15.32 minutes in 2013 (Figure 7). Reasons for the slight increase from 2011 to 2012 include technical and third-party issues and are not a consequence of increased VRE generation, according to a report from the Federal network agency ("BNetzA")[7].

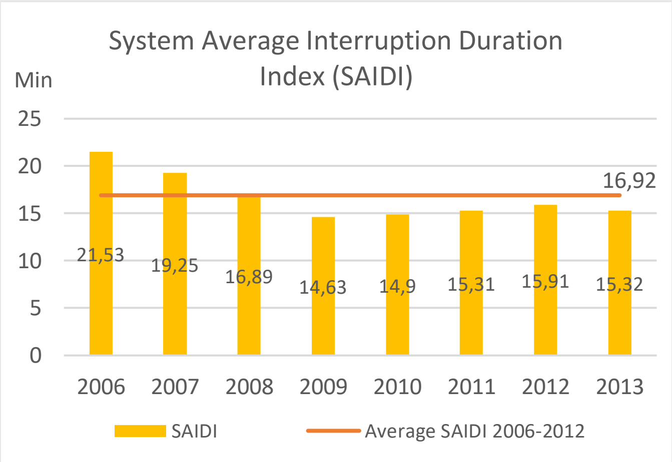

Figure 7, Source: EWI, data provided by BNetzA [8]

Delayed network infrastructure expansion causes congestion, which, in turn, results in power loop flows and transit flows[18] through the grids of neighboring countries and back into a different part of Germany. This issue has become increasingly important as more and more wind capacity has been deployed in northern Germany, while the necessary grid extensions to transfer the electricity to the south where most of the demand is located have been delayed [2][7]. In addition, nuclear power plants in southern Germany are being decommissioned due to the national nuclear phase-out, strongly exacerbating the bottleneck.

In 2005, a study was published by the German Energy Agency, which investigated the need for grid extensions in order to reach a 20% RE target by 2015 [35]. The findings were incorporated into the Power Grid Expansion Act ("EnLAG") of 2009, which specifies 1,855 km of additional extra-high voltage lines to be built by 2015 [7]. As of the first quarter of 2013, only 15% of the total planned power lines had been built, with a large amount of projects having been delayed. In Figure 8, green indicates lines that have been completed, orange indicates lines under construction, and the other colors depict lines in different stages of planning. It is expected that only 50% of the planned extensions will be completed by 2016 [7]. The four TSOs are required to publish yearly reports, referred to as Network Development Plans that present the reinforcement and expansion measures necessary to ensure continued operation of the grid for the next ten to twenty years. Each federal state is responsible for the construction of projects within the respective state, while planning, approval, and implementation is done by the Federal Network Agency ("BNetzA") [7].

[17] This indicator expresses the average duration of supply disruptions experienced by a customer over a period of one year. The SAIDI value does not take into account scheduled interruptions, nor those caused by force majeure, for example by natural disasters [7].

[18] Deviations between scheduled and physical electricity flows are defined as unscheduled flows. Loop flows are unscheduled flows stemming from scheduled flows within a neighboring bidding zone or control area, whereas transit flows are unscheduled flows stemming from a scheduled flow between two or more bidding zones or control areas [34].

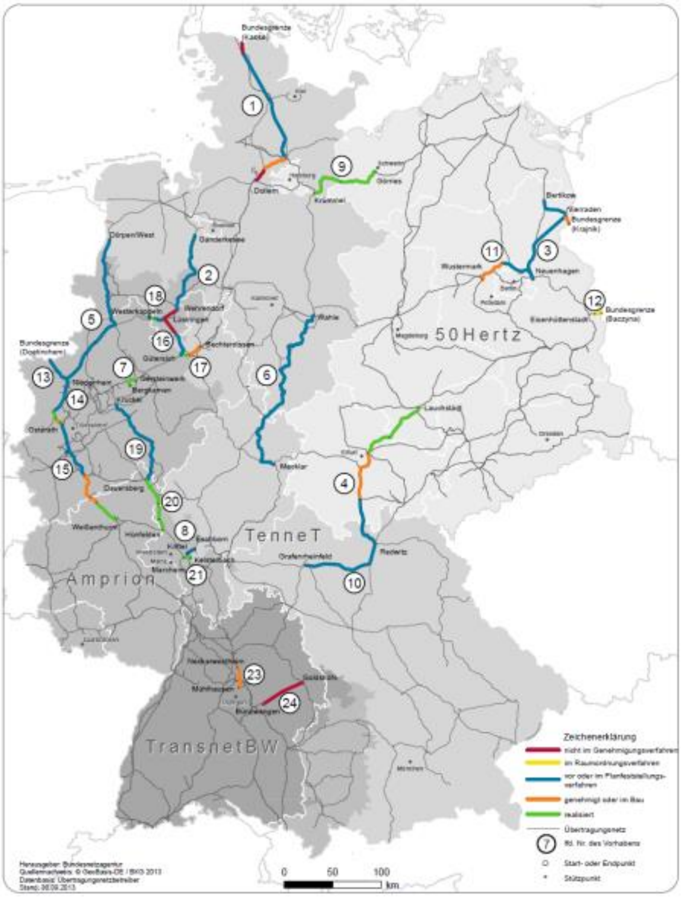

Figure 8: Network Expansion Projects: Status of the Expansion of Power Lines After the Power Grid Expansion Act (EnLAG) for the Third Quarter of 2013, Source: BNetzA [7]

Besides reinforcing the transmission network (220-380kV), the distribution network (0.23-110kV) also needs expansion measures. Reasons include end of investment lifetime of the grid infrastructure as well as the strong deployment of VRE generators. Note that RE in Germany is connected on different distribution grid voltage levels, and that both TSOs and DSOs face a legal obligation to connect any RE plant to the grid.

The German grid is interconnected with neighboring countries including Sweden, Denmark, Poland, the Netherlands, Luxembourg, France, the Czech Republic, Switzerland, and Austria. In 2012, the average available net transfer capacity to the individual neighboring markets ranged from around 400 MW (Germany-Sweden) to 4´000 MW (Germany-Switzerland). The total average net transfer capacity was at 21´735 MW, which compares to a typical domestic peak load of around 73–80 GW [7][33]. The European Network of Transmission System Operators for Electricity ("ENTSO-E"), consisting of 41 TSOs from 34 European countries, has developed a European-wide Ten Year Network Development Plan ("TYNDP") to aid the integration of renewables and establish an internal European energy market [36].

Grid Fees

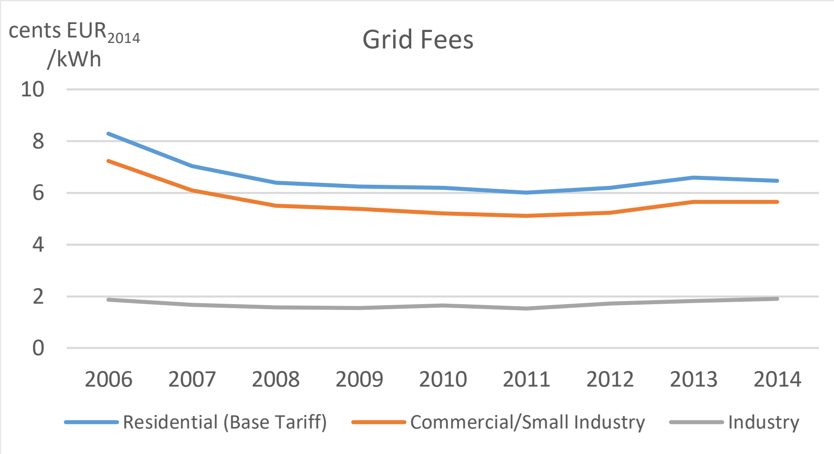

Figure 9, Source: EWI, data provided by BNetzA [8]

Grid fees are charges on a kWh basis, specified by resident. They include charges for grid utilization, grid expansion, metering and operation of metering devices. Figure 9 shows the development of grid fees from 2006-2014[19]. In 2014, grid fees for residential consumers were at 6.5 cents EUR_{2014}/kWh; 5.7 cents EUR_{2014}/kWh for commercial and small industry; and 1.9 cents EUR_{2014}/kWh for energy-intensive industry.

Exports and Imports

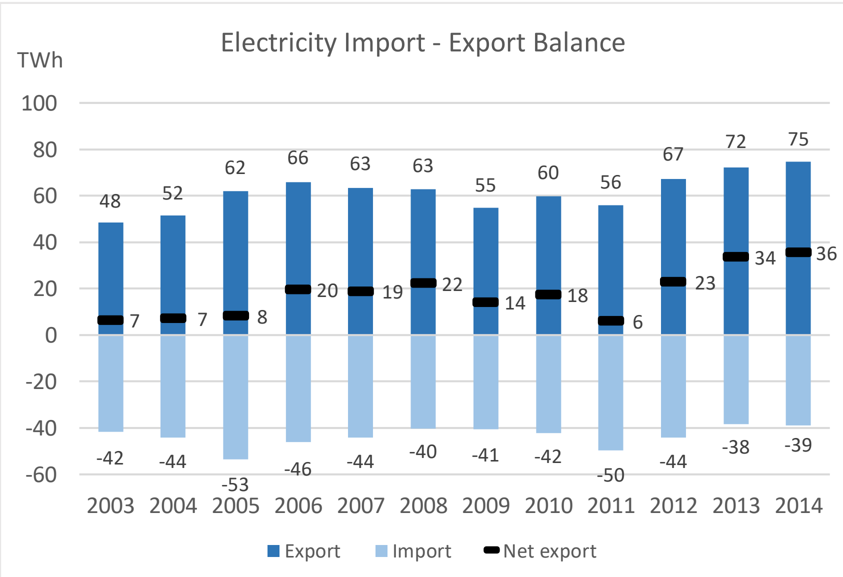

Figure 10, Source: EWI, data provided by ENTSO-E [38]

Electricity exports amounted to 74.6 TWh and electricity imports to 38.9 TWh in 2014 (Figure 10). Electricity is exported whenever the market price in Germany lies below the market price of a neighboring electricity market given the availability of cross-border net transfer capacities. Reasons for Germany's historically positive export balance lie in its competitive power plant fleet and increased VRE generation with small marginal generation costs compared to its neighboring countries. This effect is strengthened by the current remuneration scheme where VRE generation is fed into the system even if prices are below their marginal generation cost, e.g. at negative prices.

[19] Price data contained in this study has been converted into real prices, labeled EUR_{2014}, using OECD consumer prices [37].

2.4 Variable RE and the Electricity System

Instantaneous Generation

The maximum instantaneous generation share describes the maximum share of load covered by a certain type of generation technology. It gives an idea of what level RE integration has reached, how concentrated in time RE generation occurs, and, considering imports and exports, how flexible and to what extent the residual power plant fleet can ramp up and down. The maximum instantaneous share of solar and wind generation of total generation used to cover demand occurred on June 16, 2013, when PV and wind generated 71% of domestic demand. The highest instantaneous share of wind alone occurred on December 24, 2013, when wind generation accounted for 59% of demand. The highest instantaneous share of PV alone occurred on July 21, 2013, with an instantaneous share of 54%. In contrast, the minimum instantaneous share of solar and wind generation occurred on February 16, 2013, with an instantaneous share of 0.3%. The minimum share of wind generation occurred on September 4, 2013, when wind generation accounted for 0.2%. The minimum share of PV alone is 0%, because PV is not available at night.

Capacity Factors

In addition to installed capacity, generation, and the instantaneous generation shares, the average capacity utilization is an important piece of information. The corresponding (standardized) measure is given by the capacity factor.[20]

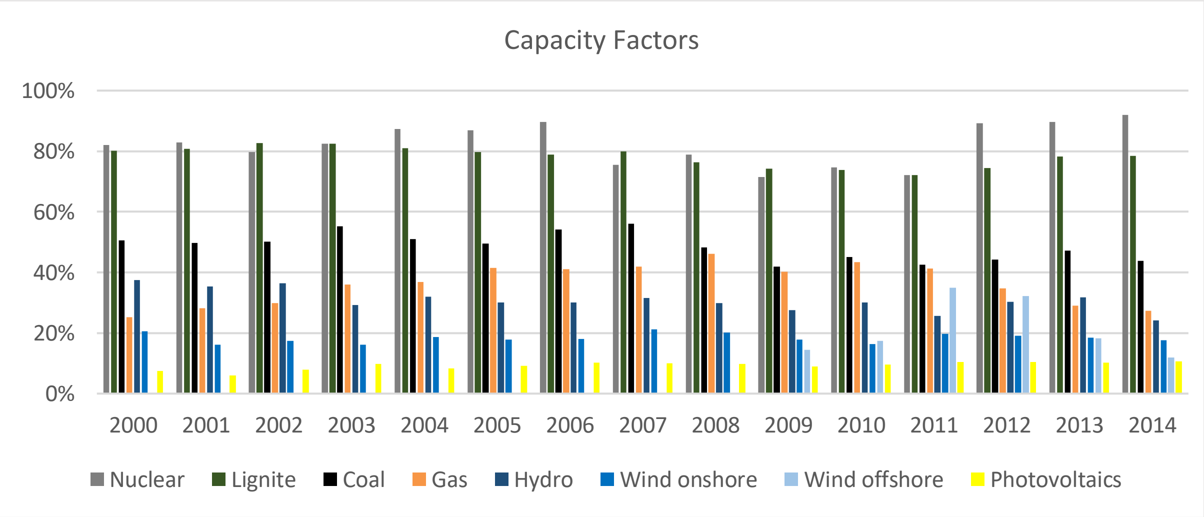

Figure 11, Source: EWI (own calculations), data provided by BNetzA [29] and BMWi [22] [27]

It indicates how much electricity a generator actually produces relative to the maximum it could produce at continuous full power operation during the same period [39]. With increasing VRE capacity like solar and wind, it is a natural consequence that the capacity factors of conventional base load

[20] The yearly capacity utilization in terms of full load hours is given by the quotient of the total yearly generation divided by the total installed capacity. Accordingly, the yearly capacity factor is given by the quotient of the capacity utilization divided by the total hours of the year.

capacity like nuclear, lignite and coal are reduced (Figure 11).[21] Capacity factors of variable renewable generators like solar and wind depend on the natural resource quality of the respective year, as well as operation and maintenance interruptions of generation. It is interesting to note that offshore wind features a considerably higher capacity factor than onshore wind due to the more steady wind speeds at sea locations. Furthermore, the capacity factor of PV varies less than the capacity factor of wind for the years considered.

Capacity Credit

Wind power as well as electricity generation from PV is not always available. Against the background of the discussion about security of supply, the capacity credit of generation technologies is a relevant measure. A capacity credit is the share of installed capacity that is available for generation at a certain level of confidence (see, e.g., [40]). Due to the stochastic nature and daily structure of wind and solar energy, the capacity credit of VRE is much lower than the capacity credits of conventional power plants. Furthermore, the capacity credit of VRE varies on a monthly and hourly basis. For example, solar energy has a daily structure and varies between different months. Hence, in Germany, the capacity credit of PV is positive at noon and is always zero at midnight. The capacity credit of PV is positive at 6 PM in June but zero at 6 PM in December. However, the usage of the term capacity credit often refers only to the capacity credit of the relevant hours regarding the annual peak demand in the market – a definition which is also used in this study. In Germany, the annual peak demand is expected to occur in winter evenings; hence, the capacity credit for PV is often assumed to be zero. The capacity credit for wind has been discussed in various studies: Depending on the confidence level and the methodology used, the capacity credit for wind power varies between 1% and 10% (see, e.g., [41], [35], [40]). In comparison, the capacity credit for conventional power plants is about 80–95% (see, e.g.,[42], [43]). Hence, in Germany, the contribution of variable RE to cover annual peak load and to ensure security of supply is relatively low compared to conventional power plants. Even if the capacity utilization of many dispatchable power plants is reduced due to electricity generation by renewables, dispatchable power plants are still needed (as back-up capacities) to ensure security of supply. [22]

[21] The increase in the capacity factors of lignite and nuclear in the years 2012 and 2013 are due to the shutdown of 8.4 GW of nuclear generation capacity in 2011, see section 3.2.

[22] Dispatchable power plants can be dispatched at any moment in time, except for certain ramp-up times; especially, they are independent of e.g. natural resource availability. Dispatchable power plants include e.g. conventional power plants.

2.5 Quality of Location

Solar Resources

The long-term average annual global horizontal irradiance ("GHI")[23] in Germany ranges from 951–1´257 kWh/m²/year, with an average of 1´055 kWh/m²/year [45] (Figure 12). Irradiance at optimal inclination is about 15% higher. However, given efficiency losses of about 15% in the PV modules in Germany depending on outside temperature, the annual GHI gives a good rough estimate of the energy yield of a PV plant in Germany. The full load hours[24] in 2012 range from 536-1´014 hours with a weighted average of 912 hours [13].

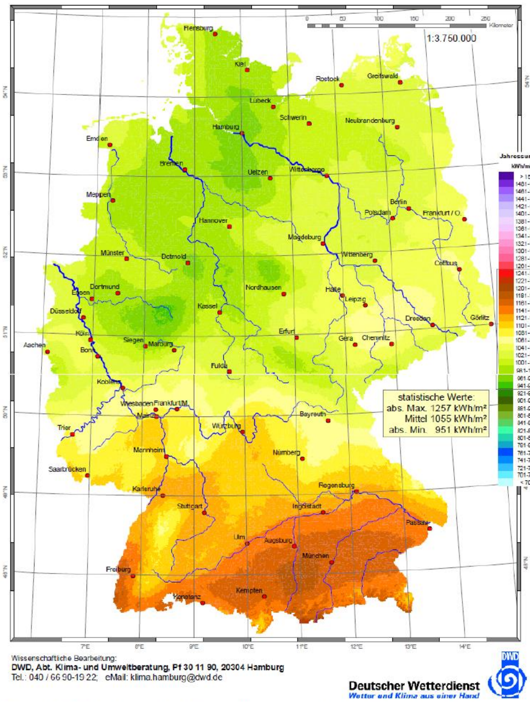

Figure 12: Average Global Annual Solar Irradiance, Source: DWD [46]

Wind Resources

Interior land wind locations see wind speeds of 3.7–7.9 m/s at a hub height of 80 m above ground. Typical onshore wind locations close to the coast feature 6.3 m/s at an 80 m hub height. Offshore wind locations range from 7.9–10.3 m/s at 80 m hub height [47]. The full load hours[25] of wind onshore in 2012 range from 1´315–2´025 hours with an average of 1´616 hours and a historical average range of 1´500–1´800 hours in the years 2006–2011. Wind offshore turbines feature full load hours of 2´800-4´000 hours [13][47].

Capacity Allocation

The installed capacity of wind and PV plants follows the distribution of resource quality in Germany. In 2012, about 80% of wind generation capacity was located in northern Germany, adding up to around 18´000 wind power plants (total around 22´200), generating a share of 82% of total wind generation. For PV, about 61% of PV generation capacity was located in southern Germany, adding up to 902´000 PV plants (total around 1´304´000) with a generation share of 65% of total PV generation.

RE Promotion and Allocation Effects

The fixed FIT, which provides remuneration on a per kWh basis, provides an incentive to build RE power plants in locations where electricity output is maximized. Thus, maximization of resource quality plays a major role in RE investment decisions. While the fixed FIT shields the RE generators from being

[23] Global Horizontal Irradiance (GHI) is the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and ground-reflected radiation [44].

[24] Full Load Hours vary from year to year, depending on natural resource quality.

[25] Id. footnote above

exposed to market prices, generators in the market premium scheme have an incentive to take electricity market prices into account for investment and generation decisions. Since spot market prices for electricity tend to be lower in times of high generation of wind and PV power plants than in times with low generation of VRE (see Section 3.1), the prices a power plant at a specific location can earn depend on whether it tends to produce when many other VRE power plants also produce, or whether it is one out of few producers. Thus, not only the full load hours of PV and wind power plants at specific locations but also the price level provide an opportunity to increase earnings. Distance of grid connection and grid congestions, however, are not taken into consideration in investment decisions under both schemes.

2.6 Electricity Prices

Wholesale Prices

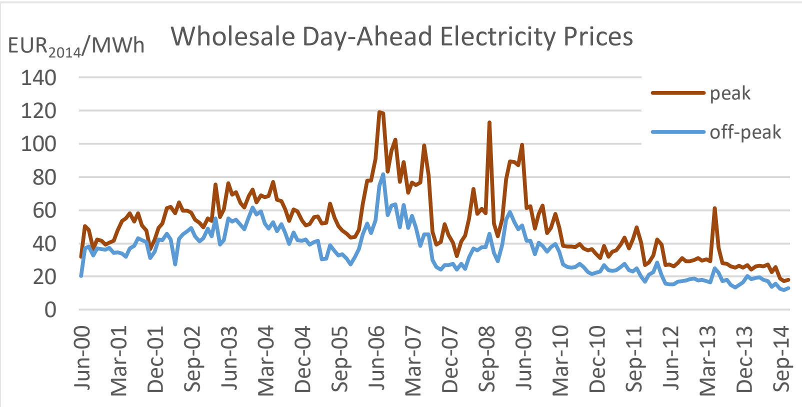

Figure 13, Source: EWI, data provided by EEX [48]

Monthly average electricity spot prices in Germany from 2000 through 2014 were in a range of 12–82 EUR_{2014}/MWh for off-peak hours (8 PM – 8 AM) and 17–119 EUR_{2014}/MWh for peak hours (8 AM – 8 PM) (Figure 13). Maximum values were reached in July–August 2006. The spread between monthly average peak and off-peak prices was in a range of 3–67 EUR_{2014}/MWh. Overall, the price spread diminished from 2011–2014 due to the expansion of low marginal cost generation (e.g. PV) during peak hours.

Retail Prices

Average residential retail prices for a 3-person household (3´500 kWh/a) were around 29 cents EUR_{2014}/kWh in 2014 (Figure 14). Electricity generation, transmission, and retail sales costs account for

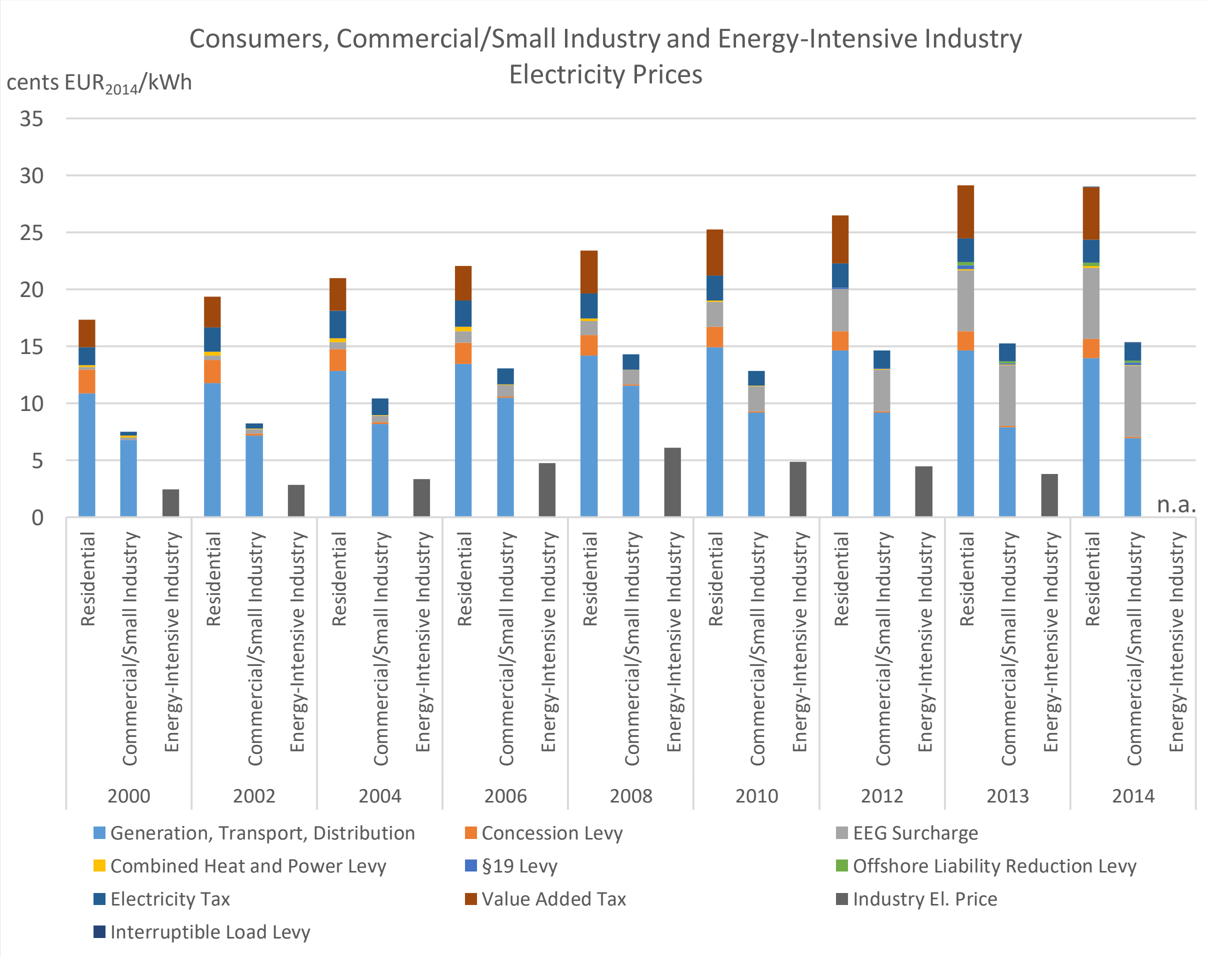

Figure 14, Source: EWI, data provided by BDEW [16] and BMWi [49]

48.3% of the electricity price, VAT[26] accounts for 15.9%, electricity tax accounts for 7.1%, concession charges[27] for local communities for 5.7%, and the EEG surcharge for 21.5%. In 2012, a new surcharge [21] for offshore wind project liability was added to the retail electricity price in order to stabilize financing conditions for offshore wind projects that experienced serious delays in grid connection during recent years. It accounted for 0.9% in 2014. The combined heat and power levy accounted for 0.6% and the §19 levy[28] for 0.03%.

Retail prices in Germany tend to be higher than in adjacent countries, mainly due to the surcharges for financing the renewable support scheme as well as the additional taxes levied. In this respect, some of the state surcharges and taxes have been reduced or omitted for certain electricity-intensive industry groups [6]. Therefore, commercial and industry electricity prices vary – among other aspects -

[26] Value added tax ("VAT") is a general, broadly based consumption tax assessed on the value added to goods and services.
[27] Concession charges are fees to be paid by grid operators to local municipalities for the right of way, i.e., for utilization of public property, like roads, for sub-surface grids.
[28] Levy for compensation of DSOs for lost revenues from individual grid charges of final consumers [50].

according to the degree of exemptions from the surcharges and taxes, which, in turn, depend on their electricity consumption and their exposure to international competition.

The average electricity price for a commercial or industry enterprise with an annual electricity consumption of 160–20´000 MWh without any EEG surcharge exemption was at 15.32 cents EUR_{2014}/kWh in 2014. Commercial and industry enterprises that were exempt from the electricity tax faced on average a tariff of 13.78 cents EUR_{2014}/kWh in 2014.

Electricity-intensive industry participants pursue different purchase strategies for electricity. As there are no official statistics on this industry group, assumptions have to be made in order to estimate average applicable electricity prices. Assuming a purchase strategy of 20% spot market and 80% forward market trades, the electricity price would be 3.83 cents EUR_{2014}/kWh in 2013 [6].

In recent years, the public discussion mainly focused on the EEG surcharge as a measure of the costs of RE promotion. However, considering the interactions between RE deployment and the electricity market, a consideration of system effects is more informative and sheds light on counteracting effects. Due to the short-term merit order effect (see section 3.1 below), wholesale market prices decreased. At the same time, taxes and surcharges increased [51]. This, in turn, benefitted those companies that were largely exempted from paying the EEG surcharge.

Legacy Cost of RE Promotion

In 2013, total EEG difference payments[29] amounted to 17.381 billion EUR_{2014} [16]. With strong decreases in FITs in recent years, a big part of current payments are legacy costs, i.e. payments for plants with higher FITs from previous years that are still within the 20-year term of the FIT. For example, the range of PV FITs granted for plants built in 2014 is 9.5–13.7 cents EUR_{2014}/kWh (see also Table 2), while the range of FITs for PV plants commissioned before 2014 spans 9.6–62.4 cents EUR_{2014}/kWh, with an average PV FIT[30] of 36.5 cents EUR_{2014}/kWh in 2012. For wind, the range of FITs for new plants built in 2014 was at 8.7–9.1 cents EUR_{2014}/kWh, while the range of FITs for older plants spans 5.2–10.2 cents EUR_{2014}/kWh with an average wind FIT of 9.2 cents EUR_{2014}/kWh in 2012 [13].

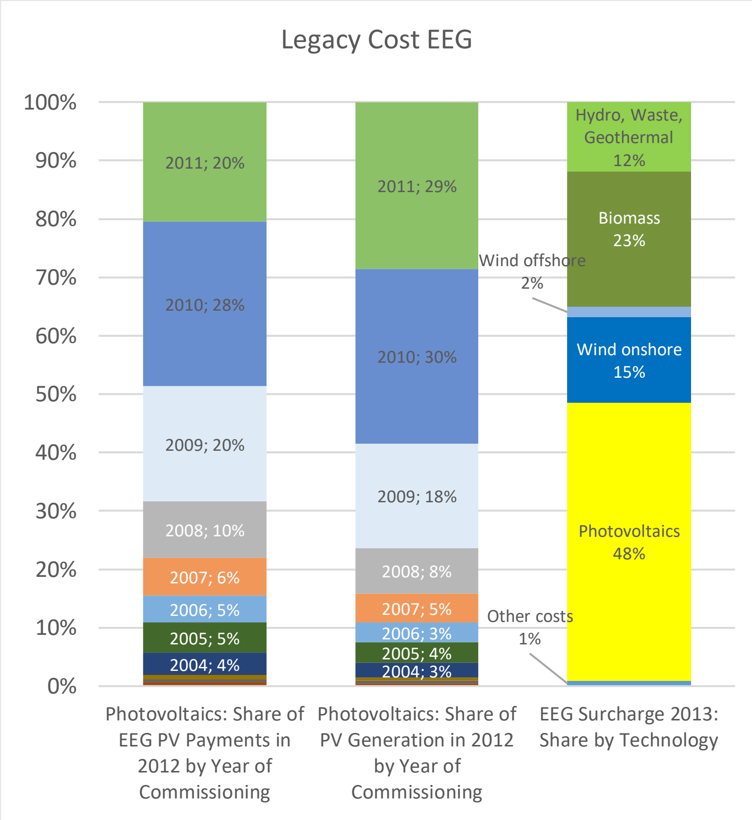

Figure 15, Source: EWI, data provided by BDEW [13]

Figure 15 shows the legacy cost structure: PV payments in 2012, which are reflected in the EEG surcharge 2013, accounted for a share of 48% in the 2013 EEG surcharge, while payments for wind onshore were at 15% (right bar in Figure 15). PV payments were based to roughly 80% on payments for plants commissioned in earlier years, summing up to the legacy costs a FIT scheme inherently brings with it as FIT are paid for a term of 20 years (left bar). While the PV capacity added in 2011 accounted for a share of only 20% of total EEG PV payments, it generated a share of around 29% of total PV generation in 2011 (middle bar). In contrast, the PV capacity added in 2009 accounted for a share of 20% of total EEG PV payments as well, however, it generated only a share of around 18% of total PV generation in 2009. This analysis shows more recently installed PV projects account for a comparably smaller share of total PV payments (left bar) relative to the electricity generated (middle bar).

[29] EEG difference payments = total EEG payments to generators - revenue from selling the electricity on the wholesale market
[30] The average FIT is given on a PV plant basis (while not weighted with installed capacity).

3 Economic Impact of VRE

3.1 Merit Order Effect

With marginal generation costs close to zero, wind and PV are likely to be among the first technologies in the merit-order[31], irrespective of whether VRE generators are granted priority dispatch – except for the particular situation of negative short-run marginal costs. The availability of additional low-cost VRE generation pushes the offer curve to the right, i.e. pushes plants with higher marginal costs out of the market, thus replacing the most expensive generators and reducing the resulting market price for electricity. These effects occur in any purely competitive environment when low marginal cost generation (such as VRE, hydro or nuclear), is added to the system. However, in this context, VRE have the special characteristic of being non-dispatchable, and thus timing and size of the shift in the merit order strongly depends on weather conditions.[32]

It is important to distinguish between the short-term and long-term impacts of VRE on the wholesale market price. While in the short term the power plant mix is fixed, adjustment processes are possible in the long term, new power plants can be built and other power plants can be shut down. Furthermore, electricity demand tends to be more elastic in the long term [52].

In the long term, growing electricity generation from VRE will lead to a lesser need for baseload capacity because the number of hours, in which an increasing part of the load is covered by VRE, will go up while reducing the full load hours of baseload capacity. Therefore, the business case for baseload capacity featuring high fixed costs is diminished, and capacities with lower fixed costs, but usually higher marginal generation costs (e.g., gas-fired power plants) are becoming more competitive [52].

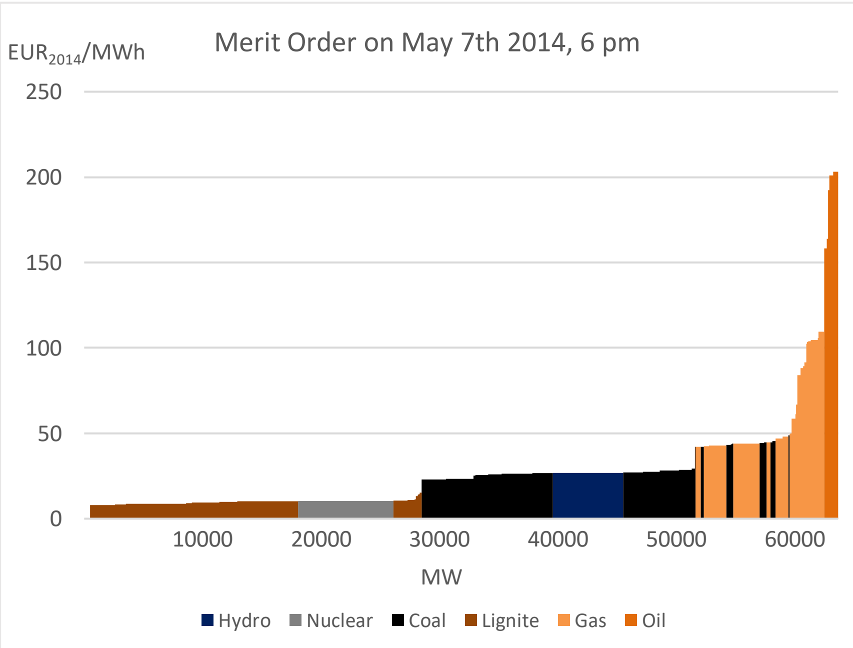

Figure 16, Source: EWI (own calculations), data provided by EEX [48]

In the short term, the merit order effect can be substantial, depending on the size of VRE capacities installed relative to the

[31] The merit order describes the ordering of power plants based on their short-term marginal generation costs.

[32] The term “merit order effect of VRE” describes the decreasing impact of VRE on wholesale prices (exchange prices). Since many VRE, e.g., wind and solar energy, have marginal generation costs close to zero, they replace the electricity generation by conventional power plants that have relatively higher variable generation costs. In hours with high generation from renewables, power plants with low generation costs determine the price.

total size of the market. The scale of the merit order effect depends on the price difference between the most expensive generation capacities that are needed to cover demand with and without electricity generation from VRE. In particular, the dispatchable power plant mix and its marginal generation costs determine the slope of the merit order curve and, therefore, the resulting price reduction from the shift in residual demand. Several other factors may influence the level of the merit order effect, including the overall level of demand relative to capacity, wholesale prices of foreign countries, the degree of interconnector capacity utilization, fuel costs, and CO_2 prices in a given year. A higher CO_2 price reduces the coal-gas spread and therefore decreases the merit order effect. Moreover, the correlation between VRE generation and load may have a large impact on the merit order effect. For example, if a period of strong wind coincides with very high load, then the reduction of demand by renewables might occur at the steepest part of the merit order curve and, thus, the price reduction is high. Conversely, the merit order effect is smaller along the flatter part of the merit order curve (Figure 16), [33] see Fürsch et al. (2012) [52]. Therefore, it is common for the merit order effect to vary from year to year see Nagl et al. (2012) [53].

Different researchers have tried to quantify the short-term merit order effect in Germany.[34] A quantification of the merit order effect is difficult and the results strongly depend on the methods used as well as on the system and price parameters of the period studied.[35] For example the merit order effect for the year 2006 was quantified by Sensfuß and Ragwitz (2007) [54], Weigt (2009) [55] and Weber and Woll (2007) [56] stating estimates of -8.85 EUR/MWh, -7.11 EUR_{2014}/MWh and -4.59 EUR_{2014}/MWh , respectively. Sensfuß (2011) [57] and Weigt (2009) [55] estimated the merit order effect in 2007 to be at -6.47 EUR_{2014}/MWh and -11.62 EUR_{2014}/MWh, respectively.

While the EEG surcharge has an increasing effect on the retail prices of many consumers (Section 2.6), the merit order effect reduces electricity market prices. Industries that are exempt from paying the EEG surcharge thus gain benefits from the merit order effect while they are only slightly contributing to the financing of the RE promotion scheme.

[33] Merit order from May 7th 2014, 6pm. Note that this merit order does not include all power plant capacities since only power plants greater than 100 MW are considered. In these calculations the nuclear power tax ("Brennelementsteuer") for nuclear power plants are included that makes generation from nuclear power plants more expensive compared to lignite power plants.

[34] See, e.g., Sensfuß and Ragwitz (2007) [54], Weigt (2009) [55], Weber and Wool (2007) [56], Sensfuß (2011) [57]. For a detailed comparison on different merit oder analyses see Fürsch et al. (2012) [52].

[35] Some authors only consider wind and/or solar energy, while others consider all VRE. Furthermore, some authors consider adjustments of the conventional power plant mix or possible import and exports while others do not.

Development of Imports and Exports

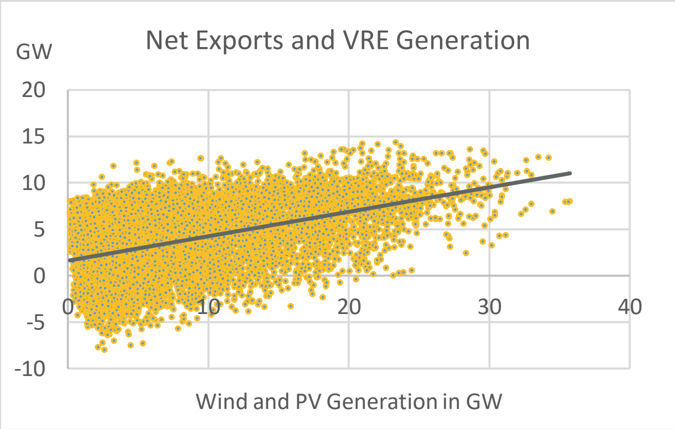

Figure 17, Source: EWI, data provided by ENTSO-E [58]

The merit order effect has a positive effect on the export-import-balance with neighboring electricity markets. It is not possible to quantify the contribution of a single generation technology to the export-import-balance. One can only draw indicative conclusions from the average generation mix in those hours where exports where high. For 2013, hourly dispatch data are only available for PV and wind generation, but not yet for all other generation technologies. There was a tendency to increased net exports when PV and wind generation was high (Figure 17). This graph, in turn, does not give any indication of how much generation of other low marginal generation cost capacity, such as lignite, was online. However, further analysis shows that net exports were high in hours of high demand where a lot of generation capacity tends to be online. This leads to the indicative conclusion that net exports were high in hours where a lot of low marginal generation cost capacity such as wind and PV – but also lignite and nuclear – was generating.[36] Also, it is expected that the single bidding zone in Germany amplifies this effect.[37]

3.2 Relevance of RE Promotion Scheme

Market Value of Variable RE

The market value is given by the weighted average spot market price that a VRE generator would receive by selling its electricity on the market.

The market value for Germany is calculated on a monthly basis with hourly day-ahead market data from EEX. For the months between June 2010 and February 2013, the market value of PV was almost always higher than the average EEX spot market price (Figure 18). This can be explained by the concurrence of hours with high demand and PV generation around noon. However, in more recent months, the market value for PV approached the average EEX spot market price. In contrast, the market value of wind power remained below the average EEX spot market price over the same period. The correlation between hours with high demand and wind power was much lower than between hours with high demand and PV infeed.

[36] EWI (2013) compares scenarios for 2013-2022 with and without further expansion of Germany's RE capacity. The authors find that the German net export balance increases by an amount equal to more than one third of the additional wind generation, or equal to more than 40 percent of the additional solar generation, respectively. The amount of wind or solar electricity actually exported differs from this percentages and could be approximated by consideration of the generation mix in the respective hours with exports [59].

[37] A quantification of this effect needs further research.

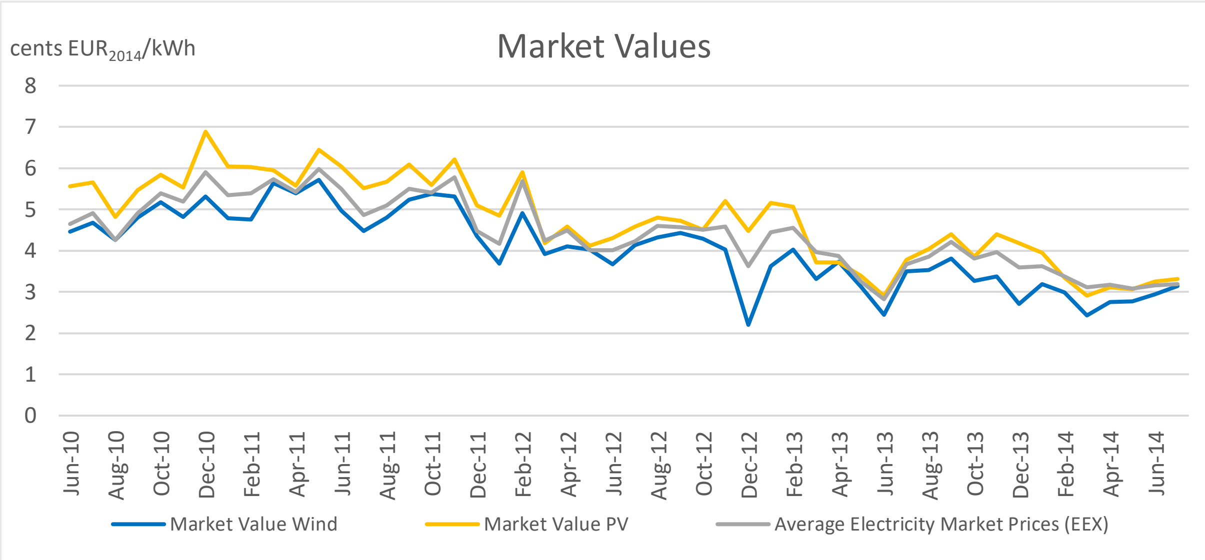

Figure 18, Source: EWI (own calculations), data provided by EEX [48]

In the literature, several analyses examine the effect of increasing VRE generation on market values. Elberg und Hagspiel (2014) find that the market value for wind power decreases with increasing wind power production [60]. Similar results are given in Hirth (2014) [61]. If there were no promotion schemes for VRE, the expected lifetime average market value would be the relevant measure to be compared with the levelized cost of electricity ("LCOE") [38] as a basis for investment decisions. In Germany´s latest RE promotion scheme, the market value is an important measure because the market premium is calculated with respect to the market value (see Section 3.2).

3.3 Variable RE Deployment without RE Promotion

In terms of the wholesale market, RE deployment depends on the relationship between the market value and generation costs of RE. PV generators, depending on the system type – ranging from ground-based to small rooftop – were faced with a LCOE between 7.9 cents EUR_{2014}/kWh and 14.3 cents EUR_{2014}/kWh at the end of 2013. Onshore wind systems currently range from 4.5 cents EUR_{2014}/kWh to 10.8 cents EUR_{2014}/kWh. Despite more full-load hours, electricity production via offshore wind today is still accompanied by higher costs, namely a LCOE range between 12.0 and 19.6 cents EUR_{2014}/kWh [47], not including the specific grid connection cost. Since March 2012, the monthly market value of wind power has been below 4.5 cents EUR_{2014}/kWh, below the lower bound of LCOE of onshore wind in Germany. However, the LCOE of onshore wind power is relatively closer to the corresponding market value compared to PV and offshore wind, where LCOE are multiples of the current market values.

With respect to the retail market, comparison of the residential electricity tariff and PV generation costs is critical when considering VRE deployment. Recently, increasing residential electricity tariffs

[38] LCOE is calculated by summing all plant-level costs (investments, fuel, emissions, operation and maintenance etc.) and dividing them by the amount of electricity the plant produced [62].

and falling rooftop PV system costs have facilitated after-tax grid parity[39] at the residential level in Germany. The flat residential electricity rate was equal to 28.8 cents EUR_{2014}/kWh in 2013, well above the generation costs of rooftop PV systems that are about 14–16 cents EUR_{2014}/kWh, see e.g., Jägemann et al (2013) [64]. Thus, after-tax grid parity may encourage households to self-consume the electricity generated from their PV systems.[40]

Self-Consumption of Electricity Generated with VRE

Self-consumption is defined as one's own consumption of self-produced electricity. In Germany, self-consumption showed an increasing trend during the last few years and was at 57 TWh in 2012 (Figure 19)[65]. Besides sinking costs for self-production generation technologies and increasing retail rates, self-consumption has been stimulated by indirect governmental incentives during recent years via tax and levy exemptions. Depending on specific pre-conditions, self-consumers are granted reductions in the EEG surcharge, grid fees, offshore liability reduction levy, concession levy, electricity taxes, and other levies. Thereby, the consumption of a self-produced kWh becomes cheaper than consuming grid-supplied kWh.

At the residential level, the majority of the self-consumed electricity was generated from rooftop PV systems. However, this only accounted for 0.1% of total self-consumed electricity in 2010 and grew to 1.3% in 2012. The largest part of self-consumption takes place in the industry sector, mostly from combined heat and power generation [65].

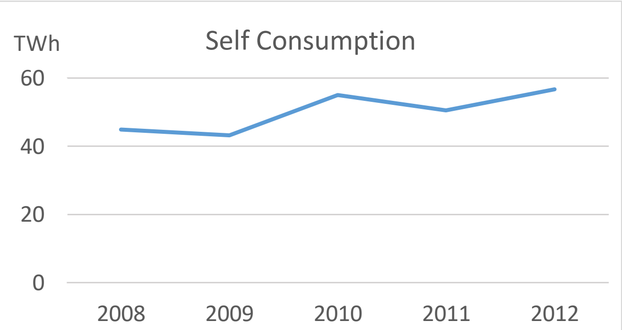

Figure 19, Source: EWI, data provided by BDEW and TSOs [65]

Without careful adjustments in regulations, this path of self-consumption of electricity may result in several negative economic effects, including uneven distribution of grid infrastructure financing as well as inefficient power plant investments and distribution effects, e.g. if a more cost-effective generation technology becomes more expensive than another less cost-effective technology that is granted the exemptions. Positive effects such as increased security of supply through greater system stability are also possible given increased flexible generation from, for example, combined heat and power ("CHP") systems [65]. [41]

[39] Grid parity is known as the point in time at which LCOE of the rooftop PV systems reach the level of the residential electricity tariff [63]. Grid parity does not necessarily indicate that investment into auto-consumption is efficient at the level of the entire economy, since retail prices often are distorted by state-induced cost components such as taxes or levies. This, in particular, is the case in Germany where state-induced cost components make up roughly half of total retail prices.

[40] The overall economic efficiency of self-consumption depends on the tariff and surcharge structure at hand and can be adversely affected by self-consumption. In light of the current tariff structure in Germany, studies found that auto-consumption is inefficient from an overall economic perspective.

[41] German policymakers have recently begun addressing this issue by extending the EEG-levy to self-consumed electricity.

3.4 VRE Impact on Economy

Gross Employment by RE Build-out

There are various estimates of gross job creation induced by RE build-out in Germany. The study EmployRES commissioned by the EU estimates total gross employment due to RE in Germany at

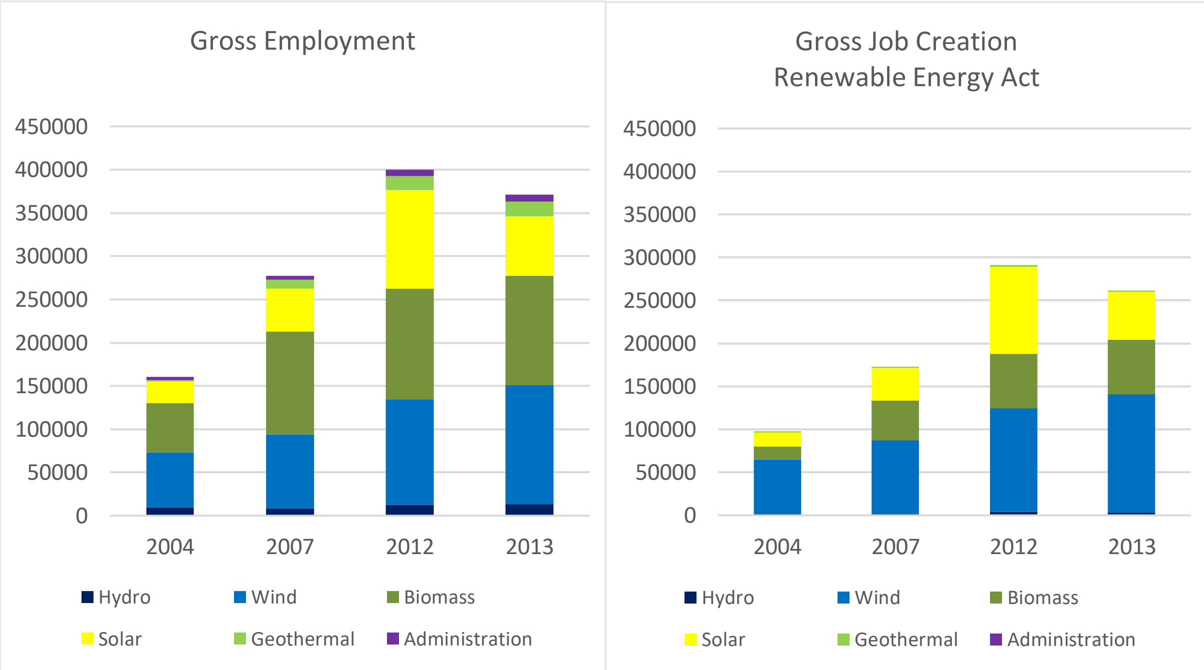

Figure 20, Source: EWI, data provided by BMWi [66]

around 320´000 in 2005 [67]. Lehr et al (2008) estimate 157´000 jobs in 2004 [68]. A long-term monitoring project of RE employment commissioned by the Federal Ministry of Economics and Energy ("BMWi") estimates gross employment in 2004 at 160´500, 399´800 in 2012, and 371´400 in 2013 (Figure 20)[66]. The research institutes involved in this analysis apply an input-output analysis using the respective turnovers in the respective industry sector, based on an input-output table by the Federal Statistical Office ("Destatis")[69]. They estimate for 2013 a share of 70% of the RE jobs, or 261´500 jobs, being a direct consequence of the EEG (Figure 20). The decrease in employment from 2012 to 2013 is explained largely due to a reduction in jobs in the PV industry. While the German market accounted for 59% of the world PV market in 2012, it decreased to 28% in 2013. Production of PV modules and cells fell by 30–40% from 2012 to 2013, resulting in a reduction of 44% in employment in the PV industry [66]. Reasons include, among others, the low complexity associated with PV production given the availability of turn-key production lines as well as industrial policy measures undertaken in Asia [45]. Lehr et al (2012) estimate a further increase to 500–600´000 jobs by 2030, depending on the scenario [70]. However, such studies need to be interpreted with caution. The number of jobs created in the RE sector in a given period is strongly correlated with the newly installed capacities in this period. Hence, at some point – e.g. when support schemes are stopped, or when the market is saturated with RE – many of these jobs will disappear. Thus, it would be important to carefully analyze the longevity of the job creation effect of the RE support scheme.[42]

Net Employment by RE Build-out and GDP

The literature provides a broad range of estimates of net employment effects due to RE deployment. Positive employment effects are documented, e.g., in Hillebrand et al. (2006) for the years 2004-2008 [71], in the monitoring project by the BMWi (in 19 out of 24 scenarios) [72], and in EWI/Prognos/GWS (2014) [73]. Hillebrand et al. (2006) predict negative employment effects for 2010 as in their model, the initial expansive effect due to investments (for the years 2004 to 2008) is offset by a contractive effect resulting from an increase in production cost of power [71]. Fahl et al. (2005) [74] and Pfaffenberger (2006) [75] also state negative net employment effects.

In addition, there is some literature about the effects of RE deployment on GDP. Positive effects on GDP (historical and in future scenarios) are estimated, e.g., by EWI/Prognos/GWS (2014) [73], in the EmployRES study [67] and in the long-term employment monitoring project commissioned by BMWi [72].

The findings in such studies are based on a number of assumptions, which are discussed e.g. in Lambert et al. (2012) [76]. In particular, potential crowding-out effects in the use of labor and capital need to be carefully investigated. Also, the German RE support scheme essentially works like any debt-financed state stimulus program, just that the debt is not repaid by the state, but by the electricity consumers. Thus, it would be important to know the economic "multiplier" associated with this investment program, and to understand the interaction between present and future direct and indirect job creation from today's investment, and present and future indirect job losses due to the cost of the support scheme.

Fuel Price Hedge

The risk structure of generation portfolios depends, among other factors, on fuel price risk. RE like wind and PV have a risk structure that is not related to fossil fuel supply risk. Thus, wind and PV can improve the risk structure of a generation portfolio and act as a hedge against fuel price risks [77]. According to Awerbuch (2006), an extensive body of research indicates that fossil fuel volatility significantly disrupts the economies of consuming nations. He argues that compared to existing, fossil-dominated generation mixes, efficient portfolios reduce generating costs while including greater renewable shares in the mix, thereby enhancing energy security [78]. A report by the U.S. National Renewable Energy Laboratory (NREL) points out that the price volatility reduction comes mostly with generation portfolios heavily dependent on imported fuels as opposed to portfolios using national fossil fuels [79]. With net import quotas for Germany in 2012 of 81% for coal, 86% for natural gas, and 98% for oil [6], and generation shares in 2012 of 18% for coal, 12% for natural gas, and 1% for oil, roughly 30% of electricity generation depends on an import quota larger than 80%. However, both

[42] The job creation effect needs to be distinguished between short-lived jobs (such as for installing PV systems under a changing support scheme) and sustainable jobs (such as in wind turbine manufacturing producing first for German demand, but being later successful in international competition).

solar and wind also exhibit significant intra-year volatility, which has to be taken into account when evaluating the extent of the fuel price hedge. Moreover, RE investments face similar exposure to demand risk as any other investment in generation capacity and any potential fuel price hedge could be fully appropriated by the market participants. With respect to the hedging value of RE, the NREL states that it is difficult and rare to be able to lock in financial or physical supply contracts of 10 years or more for fossil fuels because such contracts would include premiums that reflect lack of liquidity and counterparty risk. Such reasons may raise the physical hedging value of PV and wind that is not easily replicated in the financial and physical commodity markets [79].

Reduction of Import Bill

The EU-study EmployRES states an energy import reduction due to RE deployment worth 6–8 billion EUR_{2014} in 2012 and 8–10 billion EUR_{2014} in 2014 for the EU in the business-as-usual scenario [67]. The European Wind Energy Association states that the EU spent 558 billion EUR_{2014} on fossil fuel imports and that wind generation reduced fossil fuel costs in 2012 by 9.8 billion EUR_{2014} [80]. However, as the deployment of RE capacity carries its own price tag, such figures cannot be interpreted as pure savings, but should rather be seen in the broader context of costs and benefits of RE deployment and investments in the local economy, as well as the strategic and political benefits of a reduced import dependency. These effects, however, are difficult to quantify.

3.5 System Impact of VRE

Stability Issues

As TSOs and DSOs are required to counteract disturbances in the electricity grid, they apply network- and market-related measures. Network-related measures include network switches and are daily business for grid operators. Market-related measures take the form of congestion management measures known as re-dispatch and countertrading measures. Re-dispatch refers to intervention in the market-related schedules of generating units to prevent or rectify line overloading. Countertrading, in contrast, is a preventive reciprocal commercial transaction undertaken across control areas of the TSOs. If these measures do not suffice, grid operators use additional means to enable stability such as so-called adaptation measures to adapt feed-in, transport, and demand of electricity. Feed-in management is a specially regulated network security measure for RE, mine gas, and cogeneration installations [7].

Since Germany is closely physically connected to the grid of neighboring countries and faces internal grid constraints, loop and transit flows in neighboring countries such as the Netherlands, Belgium, Poland, and the Czech Republic have become more frequent in recent years. With scheduled flows being a result of market prices and price differences, it seems that the prices in Germany seem to trigger cross-border market flows that are not in line with physical flows. A report for the European Commission finds that loop and transit flows in neighboring countries are positively correlated to hours with high wind generation in northern Germany [34]. In fact, wind generation may create physical flows that deviate strongly from scheduled flows, in particular if the remaining generation is exposed to imperfect price signals, which do not reflect grid bottlenecks. The resulting loop and transit flows give rise to conflicts and are the subject of international negotiations, as some German neighbors consider and install physical measures to block cross-border electricity flows (via physical or virtual phase-shifting transformers).

Currently, bottlenecks within Germany are not reflected in the prices, as Germany and Austria form a single bidding zone. Partially, loop and transit flows are a consequence of incomplete price signals. Thus, splitting up the single bidding zone Germany and Austria could constitute a potential improvement [34].

Curtailment

According to the feed-in management rules, electricity produced from renewable sources must be fed into and transported on the grid with priority. Under specific conditions, the responsible network operator can scale back priority feed-in from these installations temporarily if the network capacities are not sufficient to transport the total amount of electricity generated. In particular, the restrictions on feed-in for conventional generators must first be exhausted. At the same time, network operators who are responsible for congestion are also subject to grid expansion duties. The operator of the scaled back installation is entitled to compensation for the unused electricity [7].

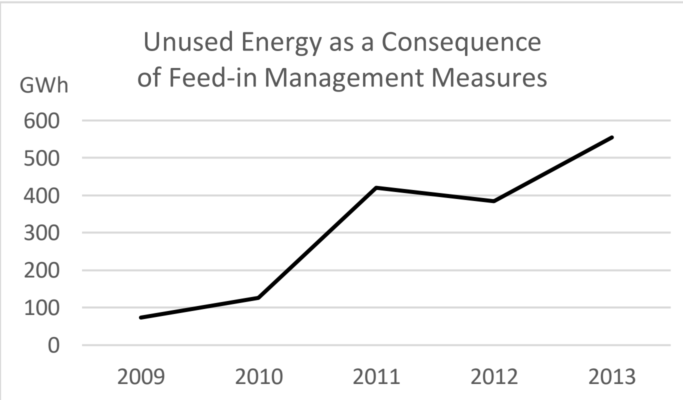

Figure 21, Source: EWI, data provided by BNetzA [8]

From 2011 to 2012, the volume of unused or curtailed energy fell from 421 GWh to 385 GWh and increased again to 555 GWh in 2013 (Figure 21). Only 2% of the curtailed generators were directly connected to the transmission network, whereas 98% were connected to the distribution network. Feed-in management at the DSO level may be issued based on instructions by the TSO or the upstream network operator, or congestion in the restricting DSO´s network [7]. The reduction in curtailed energy from 2011 to 2012 despite the strong increase in generation has several explanations, including network reinforcements and positive weather conditions with no coincidence of extreme feed-in from PV and wind power. The strong increase in curtailment from 2010 to 2011 can partly be attributed to a newly introduced declaration procedure by one of the four TSOs.

As in previous years, in 2013, wind power plants were again most affected by feed-in management, accounting for 87% of unused energy, whereas curtailed PV power only accounted for 12%. Curtailments occurred mostly in northern Germany, while in 2012, for the first time, some curtailments also occurred in southern Germany. The total amount of curtailed energy accounted for 0.66% of total VRE generation in 2013. Regarding technology-specific shares, 0.93% of wind generation and 0.21% of PV generation was curtailed in 2013 [8].

Note that curtailment of RE currently takes place for technical reasons only. Economic curtailment, or a curtailment of wind and solar in hours where the price of electricity drops below their short-term marginal production costs (which are essentially zero), does not take place because RE generators are remunerated for production even in such situations (for RE generators under the market premium scheme: until the sum of negative prices and remuneration becomes negative).[43]

Balancing Power Reserves and Ancillary Services

Ancillary services/system support services include balancing power, transmission loss compensation, reactive power provision, black start capability, national and international cross-border re-dispatch,

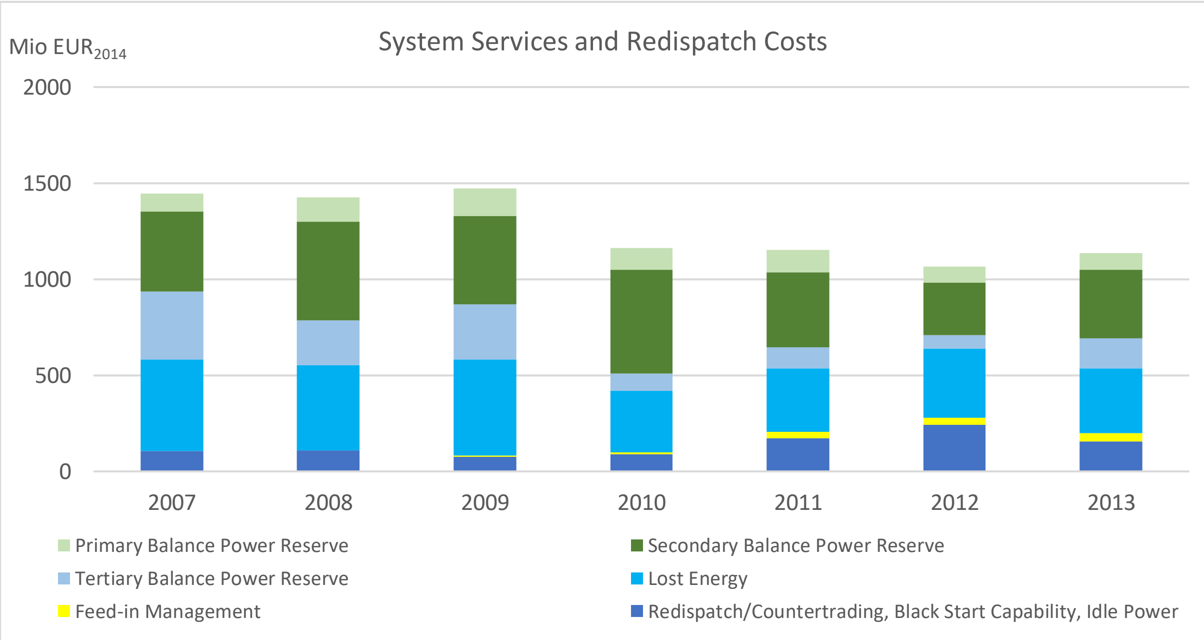

Figure 22, Source: EWI, data provided by BMWi [49] and BNetzA [8] [81] [82]

and countertrading. Since 2010, all four TSOs in Germany are part of a common balancing power market in order not to "balance against each other." This enlargement of the balancing power area has allowed Germany to reduce reserve requirements while dynamically scaling up VRE generation [7] [62]. The average capacity price for balancing power in 2012 ranged from 1–16 EUR_{2012}/MW/hour. The total costs of the balancing power requirements in 2013 was 599 million EUR_{2014}, representing a 55% share of total ancillary services cost of 1´091 million EUR_{2014} in 2013 (Figure 22) [7]. Transmission loss compensation accounted for 31%, reactive power provision for 3%, black start capability for 0.5%, and re-dispatch and countertrading measures for 11%.

Balancing Power by VRE

Given the low marginal costs of VRE, bidding of positive balancing power would induce higher opportunity costs than for a conventional generator with higher marginal cost, as the difference

[43] From 2016 onwards, RE generators do not receive any support in hours, when market prices have been negative for more than 6 hours in a row and/or for wind generators if the rated power is larger than 3MW [14].

between marginal cost and market price should be higher in most circumstances. On the other hand, as wind and PV generators can ramp down very quickly without significant increases in maintenance costs, they are well suited to bid negative balancing power. However, the current balancing power market design impedes VRE from bidding into the balancing power markets due to, among other reasons, weekly auction periods for secondary reserve balancing power, or periods for which weather forecasts are not accurate enough [83]. Also, wind power characteristics are not suitable to certain prequalification processes that are currently applied. Therefore, adjustments of the prequalification processes are under discussion and first suggestions were published in a white paper by the BMWi [84][85].

Security of Supply (Generation Adequacy)

At present, sufficient generation capacity exists in order to ensure security of supply in Germany. The installed dispatchable generation capacity in Germany currently totals about 110 GW. The maximum annual (gross) peak demand currently lies between 80 and 88 GW. Due to the integration of RE into the system, the capacity utilization of conventional power plants has been reduced. Thus, wholesale market prices are relatively low due to the merit order effect and the presence of over-capacity in the market. As a consequence, some power plants are no longer economical.

In general, plant closures do not pose a threat to generation adequacy because of the enormous overcapacity currently idle in the European market, even taking into account that Germany will close down another 13 GW of nuclear capacity by 2022. However, some of the idle capacity is located in southern Germany and might be economical if Germany were split into two or more bidding zones reflecting the internal bottlenecks inside of Germany. Correspondingly, at present, some transmission lines from northern to southern Germany are frequently subject to congestion. With the transmission system typically under greatest pressure during the winter period when low temperatures and shorter days lead to relatively high peaks in load, and with transmission network expansion projects facing serious delays, the federal network agency has started in recent years to contract so-called “winter reserve capacity” aimed at ensuring security of supply also in southern Germany where, relative to the load, less generation capacity is located. In this case, contracts are concluded with power plant operators allowing the TSOs to use the plants for re-dispatch to relieve the network [7]. The “security of supply problem,” however, for which reserve capacity in southern Germany is procured becomes prevalent mainly due to the decision to keep a single bidding zone in Germany even though there is not sufficient transmission capacity.[44] Thus, this problem is a “grid congestion problem” rather than a “generation adequacy problem.”

[44] If there were two price zones in Germany, prices would be higher in southern Germany if congestion between northern and southern Germany occurs. Due to higher prices, more power plants in the south might be economic.

3.6 Greenhouse Gas Effect

Emission Trading System and RE Policy Design

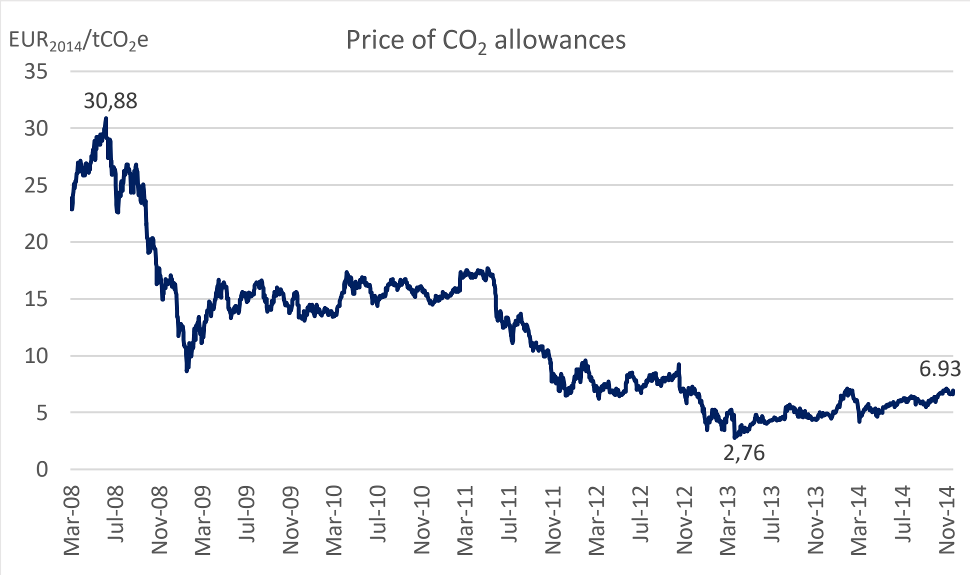

Figure 23, Source: EWI, data provided by EEX [86]

The European Union Emissions Trading System ("EU-ETS") was established in 2003 by Directive 2003/87/EC and first launched in 2005. The EU-ETS is a mandatory European-wide cap-and-trade system that seeks to mitigate GHG emissions via improvements in energy efficiency within ten energy-intensive sectors, including power and heat generation, refinery processes, coke ovens, metal ores, steel, cement, glass, lime, ceramics, and cellulose and paper. Under the cap-and-trade scheme, installations within these sectors may implement their own emissions-reducing measures or may purchase allowances for one ton of CO_2 equivalent (CO_2e) from other installations. Credits from the Kyoto Protocol's flexible mechanisms[45] may be purchased in lieu of allowances. Between 2008 and 2012, Germany received about 453 million allowances per year, with about 9% being auctioned annually and 91% being allocated freely [2]. The third commitment period is currently underway, spanning from 2013 to 2020. In 2013, more than 40% of allowances were auction, and this share will rise progressively each year. The ETS Cap is calculated on the basis of a 1.74% reduction per year from 2010 onwards. Specific sectors such as industry and heat will still be able to receive free allocation of allowances in compliance with the EU-wide benchmarks of emissions performance, based on the most efficient 10% of European facilities. Inefficient plants will therefore have to buy a greater amount of emissions allowances. The revenues from the EU-ETS are used to fund the Energy and Climate Fund, estimated to have reached 2 billion EUR_{2014} in 2013. In recent years, the certificate price has decreased for various reasons, including the economic crisis in 2008. By the end of 2013, the price was at 5 EUR_{2014}/allowance (Figure 23) [2]. Recently, it has increased again to a level of roughly 7 EUR_{2014}/allowance, partially due to decisions taken by the European Council regarding the trading period of 2020-30.

[45] The flexible mechanisms encompass the Clean Development Mechanism and Joint Implementation.

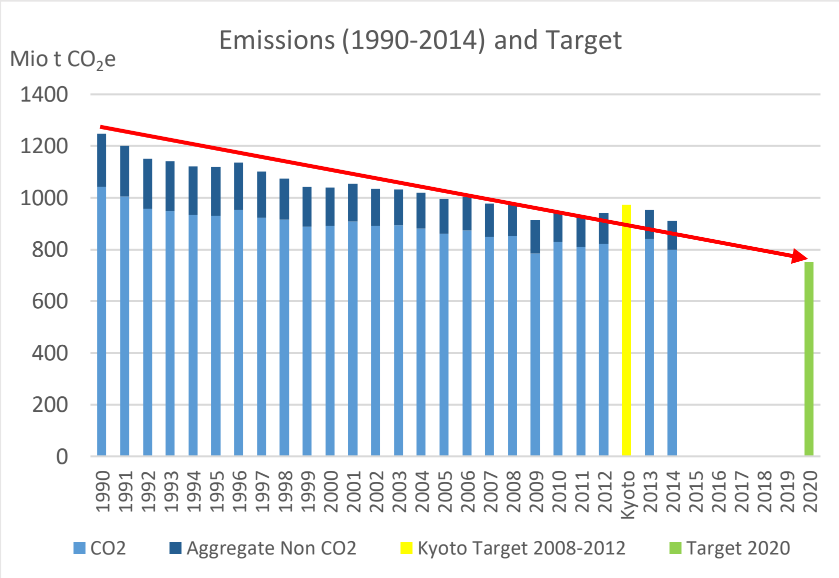

Figure 24, Source: EWi, data provided by BMU [87] and UBA [88]

The coexistence of the EU-ETS's 20% GHG reduction target by 2020, the German Energy Concept's 40% GHG reduction target by 2020 with respect to 1990 (Figure 24), and national RE targets have sparked an extensive discussion regarding overlapping regulation between national and European level policy making [2]. Jägemann et al (2013) argue that the co-existence of the RE support scheme and the GHG target without aligning one target to the other is not cost-effective. Total EU GHG emissions are not reduced by RE deployment if the corresponding CO_2e allowances are not removed from the market. Emissions are solely shifted to other sectors or countries participating in the EU-ETS. They find that a single CO_2e reduction target ensures competition among all low-carbon technologies and thus facilitates emissions reductions at minimal costs [89].

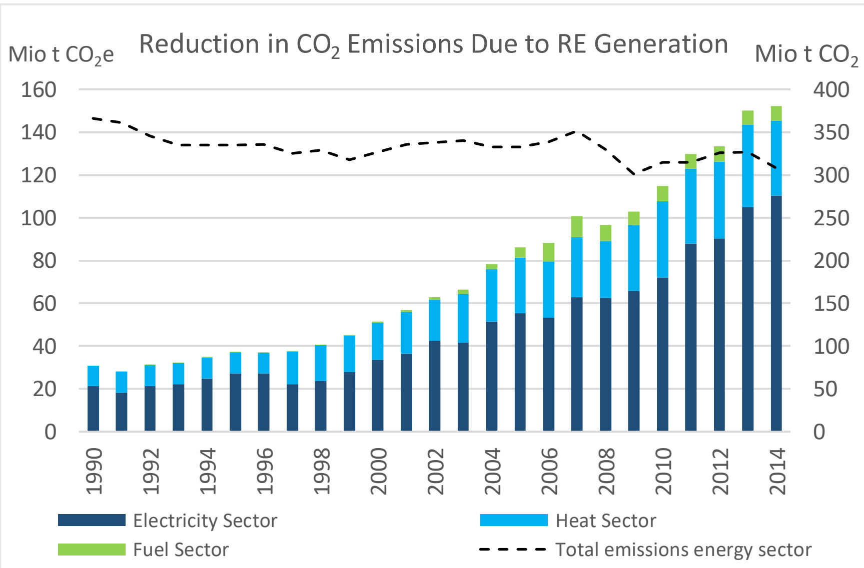

Figure 25, Source: EWI, data provided by BMWi [27] and UBA [90]

However, this argument assumes mitigation of climate change to be the single policy objective. The implementation of an emission trading system is presumably subject to political considerations, resulting in deviations from the optimal design. Gawel et al (2014), for instance, state that a GHG emissions target and a supplementary RE target could be defended as a policy mix if the EU-ETS is a result of continuous negotiations and multiple policy objectives have to be met. This might offer an explanation for additional measures such as a supplementary RE target [91]. From a sector-specific perspective, government statistics compute a gross CO_2e emission reduction in the German electricity sector due to RE deployment of 110´384 tons of CO_2e in 2014 (bar chart, left axis) (Figure 25). Overall, however, CO_2 emissions in the German electricity sector have not decreased at the same rate, partially because of the simultaneous closure of some nuclear power plants (line graph, right axis).[46]

[46] Specific emissions factors were estimated by the government at 761 gCO_2/kWh (1990), 642 gCO_2/kWh (2000) and 569 gCO_2/kWh (2014) and total emissions from the electricity sector were estimated at 366 Mio tCO_2 (1990), 327 Mio tCO_2 (2000) and 308 Mio tCO_2 (2014) [90].

4 CONCLUSION

Given the long-term goal of a low-carbon electricity sector mainly based on RE, the deployment of RE in Germany has happened fast, especially for solar PV and onshore wind, with all national renewable energy policy targets (NREAP goals) having been achieved or even overachieved. This ambitious transformation was advanced despite challenging circumstances such as high technology costs, in particular initially, comparably low natural resource quality (especially for solar), and no demand growth. The main driver of this progress has been a generous support scheme in combination with supportive price risk shifting and grid connection rules for RE investors. A liberalized market, together with an effective regulatory approach to the grid, has significantly contributed to the integration of large amounts of variable RE generation into the system. Current issues in grid stability and congestion management on the country-level are primarily due to the rapid phase-out of South-German nuclear capacity in combination with a delay in grid expansion and a single bidding zone rather than due to RE deployment.[47]

Costs of the RE promotion policy, i.e. the difference cost of the RE promotion scheme (17.226 Bn EUR_{2013} in 2013, according to BDEW [16]) and the additional system cost, remain the largest challenge of the German policy approach to large-scale deployment of renewables. In spite of further reductions expected for RE LCOE, many RE technologies will continue to struggle to become competitive at the wholesale level in Germany for years to come, especially since the solar and wind resource displays limited heterogeneity across Germany, so additional VRE capacities come at the detriment of the market value of existing VRE plants. Thus, the higher the deployment rate, the lower the market value of an additional kWh generated in the same meteorological conditions will be (ceteris paribus depending on the RE technology cost reduction and the development of the power plant fleet).

In face of this challenge, German market design has not yet been sufficiently adapted to fully support an efficient integration of VRE into the electricity market. If the speed of VRE expansion continues at currents levels, more flexibility in the system is needed. Investment in energy storage is a potential technology option to increase system flexibility and is very much discussed in Germany. However, many studies show that, due to the still high cost of storage technologies there is no strong business case for additional storage on the system level for the years to come. Further German RE deployment will therefore require significant grid expansion within Germany and at the German borders, and it will encourage both the demand and the supply side to increase their flexibility, inside Germany and in the neighboring countries.

Overall, the German government will need to maintain a RE support scheme if it wants to achieve its ambitious RE deployment targets in the foreseeable future. Thus, the absolute cost of the RE deployment program is likely to increase in the years to come (i.e. until the 20-year FIT support for legacy RE capacity expires), although the specific cost per kWh generated by VRE will further decrease in the wake of a further maturing of the global market for these technologies.

[47] RE deployment does currently create stability issues in certain distribution grids, especially in rural areas. System adjustments may relieve these issues in the future.

Without direct support, VRE are not yet competitive (with respect to the yearly average wholesale price level) and PV is only competitive in those sectors of the market where the markup to the wholesale electricity price created by the EEG surcharge and other levies and taxes is higher than PV cost (in parts of the residential and commercial sectors). In principle, this situation – the policy-induced grid parity – could trigger a substantial wave of investment in new generation capacity aimed at self-consumption, including PV with battery backup. However, such growth in self-consumption would seriously undermine the refinancing of the RE costs by reducing the base of ratepayers on which the surcharge is levied. Policymakers have already addressed this effect by including most of self-consumption explicitly into that base of ratepayers, thus making the case for after-tax grid parity investments much harder.

In summary, the German approach to RE deployment has so far led to a fast achievement or even overachievement of national RE policy targets. This progress was mainly driven by the FIT support scheme. In the short-term RE in Germany will further expand due to state-guided support. However, both in the short and long term, the German Energiewende is expected to remain the subject of vivid political debate. In any case, further changes to the design of the German electricity market – both for the renewable and the conventional part – will become necessary in the near future.

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