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The German *Energiewende* and its Roll-Out of Renewable Energies: An Economic Perspective

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ABSTRACT

The paper gives a short overview of the German *Energiewende*, i.e. the transition of a large and mostly thermal electricity system towards electricity generation from renewable energy sources. The paper discusses both, the motivation of the transition as well as future goals and current status. Furthermore, we give an in-depth view into the changes in economic costs for society as well as electricity price effects, especially for average private households and industrial consumers. We also discuss the benefits of the promotion of renewable energies in Germany.

Index Terms: *Electricity System, Renewable Energy, Cost-Benefit Analysis*

1 INTRODUCTION

Germany was among the first countries to promote large-scale deployment of electricity generation from renewable energy sources (RES) such as wind energy, photovoltaics and biomass. The process picked up speed in the year 2000, when the G*erman Renewable Energy Sources Act* was introduced. At that time, the underlying technologies were expensive and less developed. In addition to promoting RES, in 2011 the German government also decided to phase out nuclear electricity generation, shutting down all nuclear power stations by 2022. The resulting transition of the German energy system is so drastic that the German term "*Energiewende*" has been adopted by the English-speaking world and the whole process receives worldwide attention.

As a result of early RES promotion in Germany, between 45 % and 48 % of the worldwide installed capacity of photovoltaics was installed in the country between 2006 and 2010 (IRENA, 2016). As for onshore wind, Germany installed about 30 % of total global capacity in 2006. These shares decreased over time due to relatively larger investments in other countries. However, Germany installed a significant amount when RES were less developed and hence significantly more expensive than today. While the associated payments helped to bring down costs for RES due to learning, and now help to push RES investments worldwide, they imposed a significant financial burden on German society. Therefore, the transition of the German energy sector is not only a technological challenge (as is pointed out in several publications in this special issue), it also deeply impacts the economy.

The paper analyses several economic effects of the *Energiewende*. In particular, it gives a short insight into the costs and benefits of promoting renewable energies in Germany. The data focusses especially on the electricity market. Section 2 explains quantitative political goals of the energy transition. Section 3 shows the roll-out of RES in the last 25 years. Section 4 gives insight into technology-specific cost developments in the electricity sector, while section 5 shows the expenditures for different consumer groups (private households and industrial facilities) due to levies and surcharges correlated to the energy transition. Benefits of the renewable roll-out are presented in section 6. Section 7 concludes, considers how costs may change, and suggests areas for further research.

2 POLITICAL GOALS AND HISTORIC GOAL ACHIEVEMENT

The roll-out of RES is politically-justified by reasons such as limiting climate change, protecting the environment, internalizing external costs to the environment from non-renewable sources and promoting the development of renewable technologies (*Renewable Energy Sources Act* as at 2014)[1]. Further often mentioned goals for the process are the promotion of energy autarchy, job creation and abandonment of fossil and non-sustainable fuels (e.g. Joas et al., 2016).

The quantitative goals of the *Energiewende* are as follows: as mentioned above, Europe´s biggest economy phases-out of nuclear energy by 2022. At the same time, Germany will increase the shares of RES in gross electricity consumption to between 40 % and 45 % by 2025 and to at least 80 % by 2050 (see Table 1). In addition, the German government has established goals for the reduction of greenhouse gas emissions, gross electricity consumption and other energy variables in many sectors by 2050.

Table 1: Selected goals of the German government in the field of energy policies, Sources: Federal Government 2009, FMEE 2016b, FMEE 2016c, Federal Office for Motor Traffic 2016.

year	share of renewable energies in electricity consumptio n [%]	reduction of gross electricity consump-tion compared to 2008 figures [%]	reduction of primary energy consump-tion compared to 2008 figures [%]	reduction of greenhouse gas emissions compared to 1990 figures [%]	develop-ment of final energy consump-tion in transport compared to 2005 figures [%]	number of electric vehicles	reduction of heat demand (buildings) compared to 2008 figures [%]
2000	6.2	-	-	0	-	-	-
2015	**31.6**	**-4.0**	**-7.6**	**-27.2**	**+1.3**	**25,502**	**-11.1**
2020	≥ 35	-10	-20	at least -40	-10	1,000,000	-20
2025	40-45						
2030	≥ 50			at least -55		5,000,000	
2035	55-60						
2040	≥ 65			at least -70			
2050	≥ 80	-25	-50	at least -80 to -95	-40		

These goals have changed over time. Mostly, they have increased. For example, the actual goal for 2020 is that renewable energies will hold a 35 % share in total electricity consumed, but this goal has previously been significantly lower. In 2005, the German government introduced a goal to produce 20 % of Germany's electricity from renewable sources by 2020

[1] The *Renewable Energy Sources Act* is updated regularly to keep pace with market changes.

(Federal Government 2005). This goal was already achieved by 2011 (FMEE 2016b). In 2008, due to a rapid rise in the number of renewable installations, the government set an increased goal of at least 30 % by 2020 (Federal Government 2008). That goal was reached in 2015 when approximately 32 % of German gross electricity consumption was supplied from renewable energies (FMEE 2016b). Hence, Germany has a certain credibility in achieving its ambitious environmental goals, especially with respect to electricity generation from RES.

This can be confirmed by looking at the technology-specific roll-out of RES since 1990 (see Figure 1). In the early 1990s, installed hydro power capacity made up more than 80 % of the renewable capacity. In the decade from 1990 to the end of 1999, especially the installed capacity of wind power increased to 4,400 MW. By the year 2000, Germany started to profoundly support and subsidize various renewable technologies. The data shows that directly following the implementation of the *Renewable Energy Sources Act* in 2000, onshore wind, in particular, was installed and the wind installation capacity nearly quadrupled between 1999 and 2004. Installations of photovoltaic systems did not rise significantly until 2005 but increased to a great extent from 2009 to 2012. Biomass increased steadily and had a share of about 15 % of installed RES capacity in Germany in 2015. Installed capacity of hydro power remained relatively constant over time. Due to the increase in other technologies, its relative share decreased continuously. In 2015, hydro power capacities made up 5.6 GW, which was a share of about 6 % of Germanys RES capacity. For the same year, about 84 % of installed RES capacity was either from onshore wind or from photovoltaic systems. Combined installed capacity of these two technologies amounted to about 80 GW, with about half of that capacity coming from each technology. Offshore wind had 3 GW capacity (IRENA 2016). This was significantly below the other two technologies but Germany still had the second highest installed capacity of offshore wind worldwide in 2015 (after the United Kingdom).

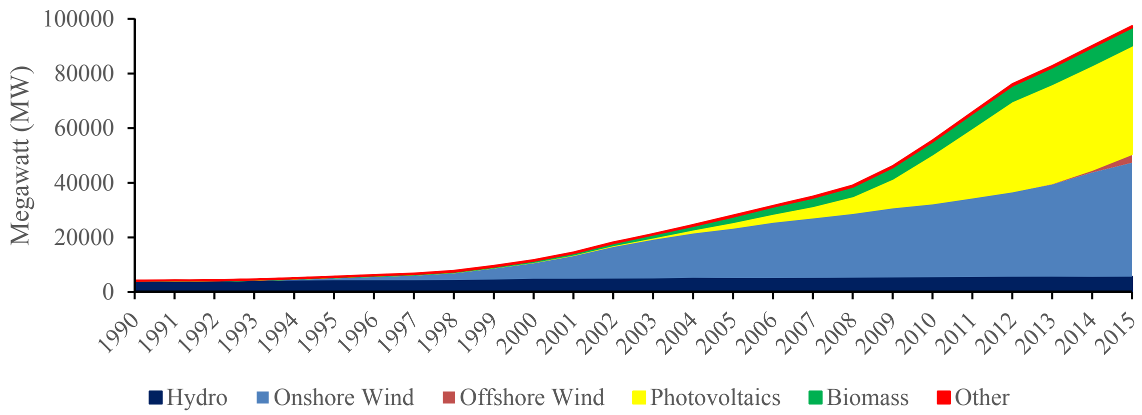

Figure 1: Installed Capacity of Renewable Energies in Germany since 1990 (FMEE, 2016b)

3 ECONOMIC COSTS

The steep increase of installation rates, especially of wind energy and photovoltaics, which was supported by the feed-in tariff system of the *Renewable Energy Sources Act* from the year 2000, brought additional costs for society and especially for electricity consumers. Increased costs resulted from the high costs attached to those new and climate-friendly renewable technologies. Three important cost parameters can be evaluated to better understand the economic effects of providing financial support for RES in Germany: Gross Costs, Market Values and Renewable Energy Support Costs.

Firstly, the support for renewable energies in the *Renewable Energy Sources Act* includes significant payments to RES generators to address the fact that most RES, having higher levelized costs of electricity production, are not competitive in the electricity market. Therefore, Germany established technology-specific remuneration for renewable electricity production (feed-in tariffs), which were determined *ex-ante* by government administrations in € per kWh. These feed-in tariffs were usually paid for 20 years plus the year of installation and fixed above wholesale market prices. The overall payments can be referred to as the **Gross Costs** of RES. For the last four years (2012 to 2015), these always exceeded € 20 billion per year, with € 27.5 billion in 2015 being the highest value so far (FMEE 2016a).

Secondly, electricity produced by RES has a **Market Value**. This value equals the product of RES electricity generation and the wholesale electricity price. The wholesale electricity price is determined on wholesale markets such as the European Power Exchange (EPEX) in Paris. The wholesale price is derived from producers selling electricity to consumers, who are mostly aggregated e.g. via municipalities.[2] Wholesale prices often differentiate by the hour, i.e. different hours have different prices. The market values for all electricity produced from RES supported by the *Renewable Energy Sources Act* amounted to approximately € 4.7 billion in the year 2015 (FMEE 2016a).

As the (hourly) Market Value of RES is the product of (hourly) wholesale prices and (hourly) RES generation, it depends on both factors. However, wholesale prices and electricity generation from RES are not independent: The more energy is produced from (intermittent) RES, which have near-zero marginal costs of production, the lower the wholesale price tends to be (*ceteris paribus*). Hence, RES electricity production and wholesale prices are negatively correlated. Therefore, the so-called market value factor of RES, which shows the average value of electricity produced by renewables energies in relation to the average annual electricity price, decreases when additional intermittent RES enter the system (see also Joskow 2011). While the electricity production of the first installed photovoltaic systems had a market value above one, as it was produced during high-priced, peak period during daylight hours, this is no longer true. Due to more and more supply from photovoltaics during daylight hours, electricity prices for power generated at this time have decreased in recent years. This

[2] Note that the underlying product is electricity. This electricity can come from all sources, for example from both RES and conventional power stations.

has lowered RES market values. As a result, the market value factor of photovoltaics decreased from 1.06 to 1.00 between 2012 and 2015 (authors' own calculation with data from Netztransparenz 2016). In the same period, the market value of onshore wind declined from 0.89 to 0.86[3]. Despite the reductions in market values generated by RES, the fixed feed-in tariff still compensates for every kWh produced.

Thirdly, the difference between Gross Costs and Market Value can be interpreted as **Renewable Energy Support Costs** (RESC)[4]. These costs in addition to the market value are the costs necessary for installing and operating RES. They are the additional costs incurred for producing "green electricity" instead of electricity from conventional sources. Figure 2 shows the development of RESC in Germany. Costs increased in recent years to more than € 20 billion annually and reached ca. € 22 billion in 2015. Out of these € 22 billion, electricity generated from photovoltaics received 44 % (€ 9.6 billion), onshore wind energy 21 % (€ 4.6 billion), and biomass 28 % (€ 6.1 billion). Offshore wind energy, hydro power and further minor technologies received 7 % (€ 1.6 billion).

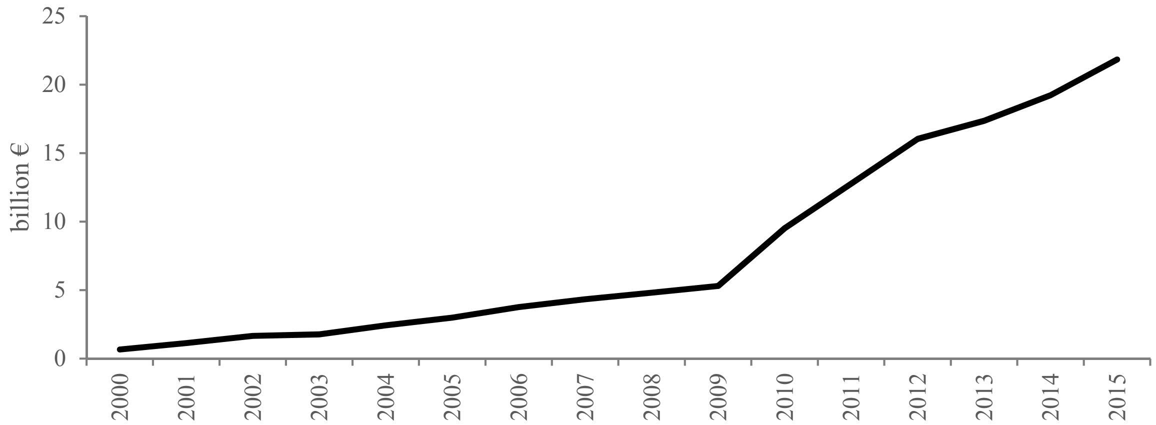

Figure 2: Annual Renewable Energy Support Costs (RESC) of subsidized Renewable Energy Sources in Germany (FMEE 2016a)

4 TECHNOLOGY-SPECIFIC COST DEVELOPMENTS

As our earlier analysis has shown, the German energy transition is mostly driven by onshore wind and photovoltaics. There are two reasons for the large penetration of these two technologies: First, both onshore wind and photovoltaics are cheaper today than other renewable technologies, such as e.g. biomass or offshore wind, due to their recent, steep cost reductions (Kost et al. 2013, Fraunhofer ISE 2015, Dillig et al. 2016). Second, despite the

[3] This effect is also referred to as self-cannibalization of renewable energies.

[4] In practice, three additional components influence RESC: (1) avoided use of grid charges and (2) the costs of the "Privilege of Green Electricity" ("Grünstromprivileg"). However, they are relatively small in comparison to the numbers shown in the graph. Thirdly (3), the costs paid by electricity consumers for RES are fixed for one year in advance to provide planning certainty for both consumers and retailers. The difference between forecasted costs and actual costs is balanced in later years. This effect shifts costs or gains caused by inaccurate estimations from one year to another, but the effect is also relatively small.

huge current roll-out of onshore wind and photovoltaics, both technologies still have huge amounts of unused technical potential in Germany. In comparison, the German Federal Network Agency attributes both hydropower and biomass lower unused technological potential (Federal Network Agency 2016).[5]

Figure 3 shows the development of feed-in tariffs for onshore wind turbines and small-scale photovoltaic systems for the period from 2000 to 2015. The feed-in tariff shown is the payment per kWh which a newly-installed facility received when starting production in that year. The feed-in tariff is usually paid for 20 years plus the remainder of the year of installation.

The graph shows that photovoltaic plants starting operations in the year 2000 received around € 0.50 per kWh. Following, tariffs were even increased by regulators in 2004 to accelerate the roll-out. Afterwards, between 2004 and 2015 tariffs for photovoltaic systems show a steep decline, from € 0.57 per kWh ten years ago to approximately € 0.13 per kWh in 2015. Therefore, new small-scale installations of photovoltaics receive only 22 % of the feed-in tariff from installations built a decade ago. For reference, this feed-in tariff can be compared with the current wholesale price of about € 0.035 per kWh. Alternatively, they can be compared with the total cost of new coal or gas fired capacity which, depending on fuel prices, investment costs and CO_2-emission costs, are roughly at € 0.06 per kWh.

The feed-in tariff scheme for onshore wind is slightly more complicated as it consists of (1) a high starting compensation payment and a (2) lower final compensation. The development of both tariffs can be found in Figure 3. At least for the first 5 years of the 20-year period of feed-in tariff payments, all onshore wind energy plants will receive the higher starting compensation. For how much longer the starting compensation will be paid to a specific wind turbine is related to its specific wind yield or, being more specific, of the relation to a fixed yield of a so-called “reference location” with a specific height and wind speed, which is fixed at 100 %. The extension of the starting compensation relates to the difference between the wind plant’s specific situation and the reference yield. Therefore, the average feed-in tariff of a wind turbine in Germany does not just depend on the year of installation, but also on the specific wind yield. Wind turbines with a very low wind yield get the starting compensation for the whole period of 20 years. The purpose of this regulation is to strengthen financial support for wind installations in less profit-yielding regions and thereby support a more regionally distributed wind energy development. Compared to photovoltaics, the value of the feed-in tariff for onshore wind has remained relatively stable (see Figure 3). While the starting compensation decreased from about € 0.091 per kWh in 2000 to € 0.085 per kWh in 2015 (-7 %), the final compensation decreased from about € 0.062 per kWh to about € 0.046 per kWh (-26 %).

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5 Federal Network Agency (2016) gives scenarios for the grid extension plan in Germany, which shows possible roll-out scenarios for different RES technologies in the next two decades.

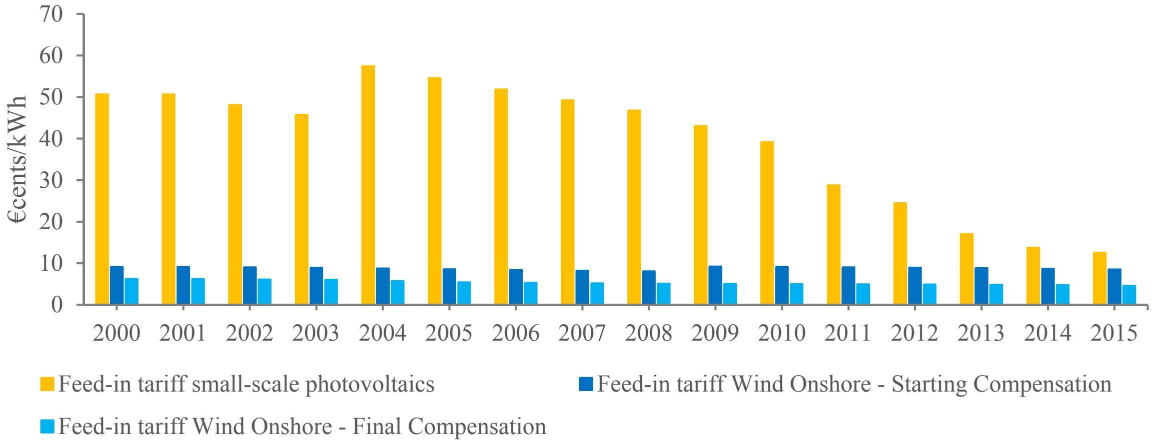

Figure 3: Feed-in tariff development for onshore wind and small-scale photovoltaic systems (TSOs 2016)

5 CUSTOMER EXPENDITURES

To finance the additional costs of renewable energies, i.e. the RESC of more than € 20 billion per year discussed above, German electricity consumers pay a fee per kWh consumed (renewable surcharge). In principle, all consumers – industrial, commercial and domestic – pay this surcharge for every kWh consumed. However, the fee is significantly reduced for consumption by energy-intensive companies. This discount was introduced to avoid a reduction in competitiveness of industries in international markets (where companies from other countries tend to have lower electricity prices and, in particular, lower RES support fees). As a consequence, the cost distribution between different types of consumers is not proportional to their consumption.

The first part of Figure 4 gives the proportion of electricity consumed by certain sectors in Germany. The industrial sector consumes almost half, while private households consume only one quarter. Compared to these figures, the second part of Figure 4 shows which shares of the predicted RESC (€ 21.8 billion for the year 2015) are paid by the respective consumer groups. More than one third of the costs – the greatest share – is paid by private households (€ 8.1 billion), while industrial customers – the heaviest consumers – just pay 30 % (€ 6.6 billion). Seventeen percent of the costs are paid by small-scale commerce, trade and services (€ 3.8 billion). Public institutions paid € 2.6 billion, while the agriculture and transport sectors have minor burdens of € 500 million and € 200 million respectively. These payments are part of the electricity price (in € per kWh). Therefore, supporting renewable energies in Germany increases electricity prices to the consumer. As households and industrial consumers pay different fees and have different costs, such as with respect to network charges, we will analyse these two groups separately.

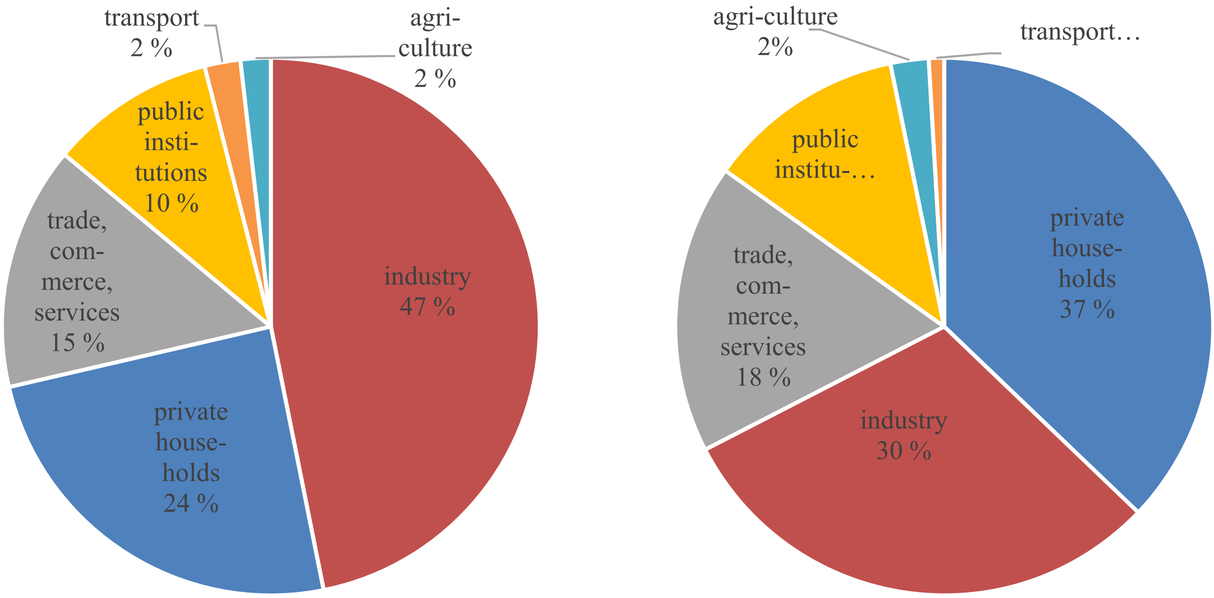

Figure 4: Share of electricity consumption (first circle) and share of RESC burden (€ 21.8 billion) (second circle) paid by different consumer groups in 2015 (BDEW 2016a, BDEW 2016b)

Figure 5 shows the development of electricity prices for the average German **private household** in € per kWh since 1998. As the data shows, all cost components increased. However, especially in recent years, the costs for the promotion of renewable energies rose significantly. In 2015, the household price is about € 0.29 per kWh. This price includes all cost components, in particular costs of electricity generation, grid costs, wholesale and retail costs, the renewable surcharge as well as all other taxes, fees and expenses. In 2015, the renewable surcharge amounts to € 0.062 per kWh (about 22 % of a customer's average price for electricity). If we account for further costs associated with the general process of transforming the energy sector in Germany, the value rises to approximately € 0.064 per kWh, represented by the green section. In addition to the renewable surcharge, this value includes costs for the promotion of combined heat and power plants (CHP), as well as the offshore wind liability levy. Comparing German household electricity prices with other countries shows that for the year 2015 Germany had the second highest electricity prices in Europe, after Denmark (Eurostat 2016). The European Union average – comprised of 28 European countries – is approximately € 0.21 per kWh, about 25 per cent lower than German prices.

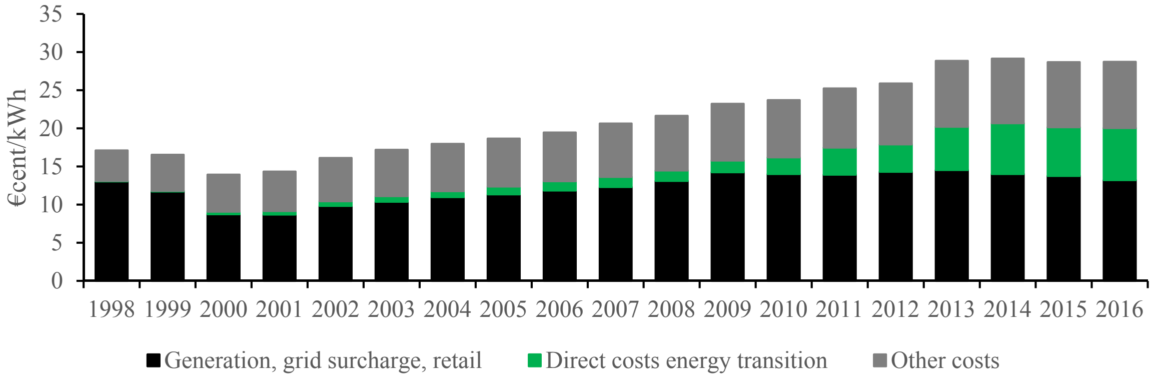

Figure 5: Electricity prices for an average German private household for the years 1998 to 2015 (BDEW 2016b); Green sections represent the direct costs of the energy transition: Renewable surcharge, CHP surcharge, Offshore liability levy; Black sections represent the costs of electricity generation, grid surcharge, wholesale and retail costs; Grey sections represent all other costs: e.g. further surcharges and taxes.

Figure 6 shows the electricity prices for industrial consumers. The cost of generation, grid and retail fees (black section) declined in recent years to only slightly higher than 15 years ago. Although the trend in cost to industrial consumers is comparable to the prices for households, a higher percentage of the industrial sector's energy costs are attributable to the energy transition (green section). During the last three years (2013 to 2015) more than 35 % of industrial electricity prices have been related to financial measures supporting the energy transition, reaching 44 % in 2015. In the year 2000, when the Renewable Energy Sources Act was first implemented, only approximately 5 % were related to that component. Now, compared to other European Union nations, German industrial electricity prices are one of the highest. While Italy and the United Kingdom are the only big economies with slightly higher prices, for industrial consumers the average cost within the European Union is € 0.12 per kWh – approximately 11 % lower than German prices (Eurostat 2016).

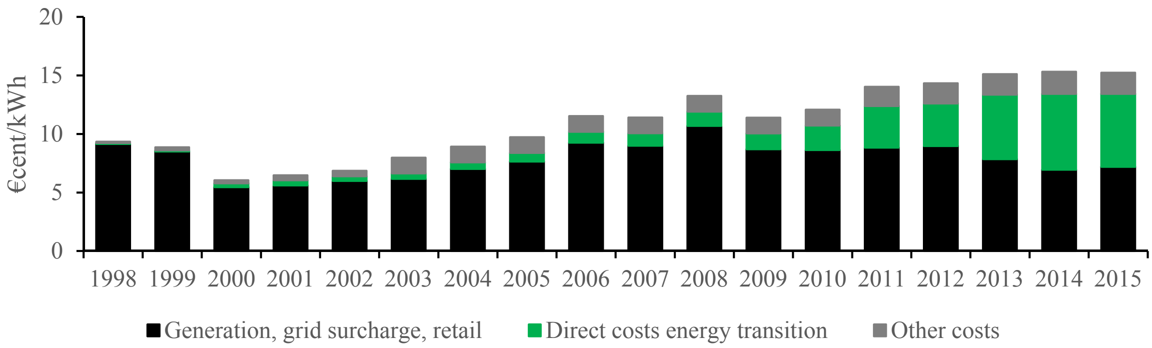

Figure 6: Electricity prices for an average industrial consumer in Germany between 1998 and 2015 (BDEW 2016b) Green sections represent direct costs of the energy transition: Renewable surcharge, CHP surcharge, Offshore liability levy; Black sections represent the cost of electricity generation, grid surcharge, wholesale and retail cost; Grey sections represent all other costs: e.g. further surcharges and taxes.

6 ECONOMIC BENEFITS

The large scale roll-out of renewable energies in Germany is responsible for the economic costs discussed in the last sections, but it also leads to several benefits. Numerous papers were published in recent years which evaluate and quantify various economic benefits resulting from RES. Some of these consider the German context, others have an international perspective. Although there is a debate regarding which elements are useful benefits of a renewable roll-out (see e. g. Borenstein 2012 and Schmalensee 2012), the following benefits are widely discussed and often mentioned in the German case:

- Correction of negative environmental externalities related to fossil fuels;
- Correction of negative Research and Development (R&D) externalities (i. e. market participants invest too little in RES for fear of other companies copying advances);
- Reduction of primary fuel imports; and
- Effects on employment.

RES reduce negative environmental externalities. In contrast to electricity generation from fossil fuel combustion, RES do not contribute to global warming in a meaningful way and emit significantly lower levels of harmful substances such as particulate matter (respirable dust), NOx and SO_2.

Furthermore, there are negative externalities for investment in R&D. These result from the spillover effects of investment in R&D: any single company investing in R&D also provides knowledge to other companies both within the country and beyond. However, as any company deciding on R&D is not taking these spill-over effects into account, which are positive from an economic perspective, R&D investment is inefficiently low. Hence, German RES support reduces these negative externalities.

Furthermore, Germany has a high import dependency in energy resources. The majority of hard coal (89 % of domestic consumption), natural gas (89 % of domestic consumption), Uranium (100 % of domestic consumption) and oil (99.5 % of domestic consumption) is imported from other countries (FMEE 2016c). The two noteworthy exceptions are the greenhouse gas emission intensive lignite stock and climate friendly RES. Both are produced within Germany, and the import share for each is 0 % of domestic energy production, with exception to some elements of imported biomass, like bioethanol or palm oil. A high import dependency has at least two disadvantages: the first is the costs of resources imported, and the second is a higher risk of supply interruption. The total amount of costs for German energy imports was € 90 billion in 2015 (Öko-Institut 2016). This number is heavily influenced by fluctuating costs for oil imports which have a share of more than half of the total. In comparison, about € 8.8 billion of primary fuel import costs were avoided for the year 2015 due to renewable energies (including renewable technologies for heat and transport).

In the year 2015, 330,000 people were employed directly or indirectly because of renewable energies in Germany (FMEE 2016c).[6] We refer to this as gross employment effect. However, when evaluating the effect of the aforementioned RESC on employment, the net employment effect due to RES is more important. Estimating the net employment effect takes into account how additional RES employment and associated RESC influence other employment capabilities. These might result from replacing other energy resources and their value added (e.g. coal or gas). Those energy sectors most likely lowered their investment activities and therefore suffered employment losses in comparison to a counterfactual scenario without (or at least lower) RESC. Furthermore, purchasing power is reduced due to higher electricity prices for consumers (see section 5). Finally, the overall employment effect depends on the factor intensities of labor and capital in renewable on the one hand and thermal power generation on the other hand. The net employment effect seems relatively small in comparison to the aforementioned RESC of € 22 billion in 2015: Blazejczak et al. (2014) estimate that in 2010, between 44,000 and 72,000 jobs can be calculated as positive net employment effects for Germany. Lehr at al. (2015) and Lutz et al. (2014) show comparable results for 2015 with 50,000 and 10,000 jobs created. Conversely, Frondel et al. (2010) estimate even negative net employment effects, which would mean that more workplaces are vanished than created by the support of RES.

7 CONCLUSION AND OUTLOOK

Germany was one of the first countries that invested heavily in renewable technologies such as wind, photovoltaics and biomass. This support was effective: both installed capacities and energy production from RES increased significantly. However, efficiency of RES promotion was limited. One reason for this is that the support scheme did not focus on the cheapest renewable technologies. Instead, high, specific feed-in tariffs promoted investment in relatively expensive technologies such as early photovoltaic systems and biomass.

The steep increase in total installed RES capacity, in combination with this inefficiency, led to high economic costs: the gross costs of RES amounted to € 27.5 billion in 2015. The produced electricity had a wholesale market value of € 4.7 billion. Hence, the 2015 RESC amounted to approximately € 22 billion, after further deducting avoided use of grid charges by RES, caused by their avoided electricity feed-in in higher grid levels. This amount of Renewable Energy Support Costs is the additional cost of producing 161 TWh from RES in 2015, as opposed to from other energy sources.

Due to the framework of the RES support system, which guarantees most RES installations feed-in tariff payments for twenty years plus the year of installation, short-term reductions of RESC for German consumers are unlikely. However, cost reductions will occur when old and expensive renewable installations leave the current support mechanism. This effect, which will start in the year 2021 at the latest, will reduce costs to consumers.

[6] Compared to 800,000 currently employed in the German automobile industry.

In terms of advantages, German investments in renewable energies compensate negative externalities on the environment, in particular pollution and global warming. Furthermore, the support scheme compensates externalities in research and development, import dependencies for primary energy imports are reduced and net employment levels may improve slightly.

We leave for further research the question by how much German RES investment helped global climate protection by financing learning effects resulting from the high number of domestic installations, most likely in the photovoltaics sector. Furthermore, we also leave a quantification of benefits and the final comparison of costs and benefits ("Was it worth it?") for further research.

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