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The German "Energiewende"—An Introduction

CHRISTIAN VON HIRSCHHAUSEN[a]

ABSTRACT

The German government's multi-decade effort to transition to a low-carbon, renewables-based energy economy is now commonly known as "energiewende" ("energy transition"). The transition has four major objectives: increasing the share of renewables to at least 80% (in electricity) and 60% for total final energy consumption, reducing greenhouse gas emissions by 80-95% (basis: 1990), phasing out nuclear energy by 2022, and increasing energy efficiency significantly; the government also encourages broad public participation in energy policy discussions and profit sharing. This paper reviews the major events leading to the decision to go "energiewende" in 2010/11 and the ensuing developments in the electricity sector. We survey the rapidly growing body of literature on the German energiewende and place the other core papers of this Special Section of EEEP in perspective.

Keywords: energiewende, low-carbon transformation, Germany, survey

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INTRODUCTION

In 2014, wind and solar photovoltaic electricity generation capacities in Germany, almost 40 GW each installed, are hitting record levels and will provide—with other renewable energy sources such as biomass and hydro—almost 30% of yearly electricity consumption (~160 TWh over 530 TWh). Whether or not one considers the achievements so far a success, they stand in striking contrast to the "fact" that most of us were taught in energy economics classes in the 1980s, e.g., that "for technical reasons, an electricity system cannot accommodate more than a 4% share of renewables."[1]

Germany is now undertaking a multi-decade effort to base the country's energy system to the largest possible extent on renewable energy sources, primarily onshore wind and solar PV, and to phase out the use of nuclear and fossil fuels to generate electricity. This technical-economic-political project is commonly called "energiewende" (Wende = turn, turnaround) and has received strong parliamentary and public support. When Jean-Michel Glachant, Chief Editor of EEEP, asked me to produce a Special Section on the topic, I viewed his invitation as an opportunity to highlight some of the salient issues for the global EEEP readership. In fact, having surpassed 25% of electricity consumption from renewables in 2013, the energiewende is entering phase 2, with the objective of achieving 50% renewables by the early

1. Advertisement by the electric utilities, in the Süddeutsche Zeitung, 1993, Nr. 152.

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2030s. What may have looked like a temporary epiphenomenon is now reaching maturity, and this is a good time to take stock.

The energiewende comes at a time where many countries are pondering how to move to lower carbon energy systems. The European Union is still pursuing its decarbonization objectives of a 40% reduction of GHG by 2030 (reference: 1990), and longer-term (though not binding) of an 80–95% reduction.[2] In the U.S., the Obama administration has launched an ambitious program to foster renewables, and the entire U.S. power sector will likely see more coal plant retirements under the federal Clean Air Act (Burtraw, et al., 2014). Even in Asia, the region with the highest energy consumption growth rates, countries have identified the need for more environmentally sustainable energy strategies.

It comes as no surprise, therefore, that the energiewende is being followed by interested parties throughout the world—those who delight in its potential and those who view policy-making with scepticism about the economic costs and the financial sustainability. The German energiewende is a unique political-historic event that cannot and must not be transposed to any other country or region; yet it offers lessons from a live experiment of turning a large-scale, conventional electricity system based on coal and nuclear energy, into a renewables-based energy and electricity system. It is in the spirit of "what has worked and what has not" that this Special Section of EEEP presents the lessons learned so far and outlines the next steps.

The remainder of this chapter is structured as follows. Section 2 clarifies the notion of energiewende and recalls the events leading up to the Parliamentary votes in 2010/2011. Five years into the discussion process, and three years after the Fukushima Daiichi nuclear disaster, considerable progress has been achieved, but the objective of a decarbonized economy is still some decades off: Section 3 assesses the early years, and checks whether the goals initially set out have been achieved, including elements of a cost-benefit analysis, and Section 4 introduces the three core papers of this Special Section; Section 5 concludes.

THE EMERGENCE OF THE ENERGIEWENDE

From the "wende" discussions in the 1970s . . .

Discussions about the energiewende started as early as the 1970s. Even though the term "energiewende" refers to the events in 2010/2011, the discussions about an alternative path of energy policy, beyond nuclear and fossil fuels, goes back to the post-1968 movement. In the context of a monopolistic, large-scale electricity industry, energiewende became a political buzzword for more democratic control, environmental activism, and the public's opposition to the nuclear sector. Erhard Eppler, a left-wing SPD-leader and the federal Minister for Economic Cooperation, first established the notion of the "wende" in his book, "End or Turnaround. Of the necessity to do the feasible."[3] The first mention of energiewende appears in the book by Krause, et al. (1980), entitled, "Growth and Wealth without Oil and Ura-

2. European Commission (2014): A Framework for the European Climate and Energy Policy 2020–2030. (COM(2014),15final).

3. "Ende oder Wende. Von der Notwendigkeit des Machbaren", own translation, DTV Deutscher Taschenbuch. München.

nium."[4] Driven by the Club of Rome philosophy, the idea of unsustainable use of fossil resources was widespread; and so was the hostility against nuclear power.

In Germany, renewable energy sources have played an important role early on. As a result, the idea of an energy turnaround included ambitions to push and expand the use of renewable resources. After the Chernobyl nuclear disaster in 1986 the conservative government under Chancellor Helmut Kohl and Environmental Minister Prof. Klaus Töpfer implemented the first "law on feeding in renewables" in 1990.[5] This law followed the suggestion formulated by the European Commission to spur renewable energy, and it adopted a classical feed-in approach (Theobald and Theobald, 2013, p. 495).

The movement gained strength after the first appearance of the Green Party in the German government (Schröder-Fischer). Jürgen Trittin, a leading figure of the Greens, became Minister for the Environment, and obtained all dossiers relating to renewable energy, vis-à-vis the Economics Ministry, that was traditionally responsible for energy policy. The dichotomy in the early days of German renewables policy may in fact, be a fundamental reason for its success. The 2000 Renewable Energy Act (EEG) continued the tradition of the StrEG, as a feed-in, technology-specific, and long-term (20 years) support mechanism for renewables (mainly wind, solar PV, geothermal, and later complemented by regulation on bioenergy). Another tangible result of this political movement was the nuclear phase-out decided in 1998, and implemented by a corporate agreement with the nuclear industry in 2002.

. . . to the energiewende in 2010/2011

However, this first nuclear phase-out was reversed by the conservative government coming into power in 2009. To sweeten the 2010 lifetime extension of Germany's nuclear reactors (by 8–14 years, according to age), the government added some "green" elements into the decision such as increasing the share of renewables, and setting GHG emissions targets. Thus was erected pillar one of the energiewende. Tragically, it took another decade to confirm pillar 2: on March, 11, 2011, a tsunami severely flooded and damaged the Fukushima Daiichi nuclear power plant, almost causing the meltdown of several reactors and contaminating the site for many years to come. On March, 14, 2011, Chancellor Angela Merkel declared a closure on Germany's seven oldest nuclear plants that would be followed by phasing out nuclear entirely by 2022.

Surprising some observers, the change of government after the September 2013 federal elections did not modify federal energy policy or the energiewende's objectives. The coalition treaty of the so-called "Grand Coalition" of Christian Democrats and Social Democrats—holding a majority in Parliament of more than two thirds—has broadly confirmed the objectives, confirming that energiewende was here to stay, and dissipating any doubts introduced that a nuclear phase-out can be reversed.

Concrete objectives of the energiewende

For the remainder of this issue, the term "energiewende" comprises mainly decisions taken between September 2010 and June 2011: Phasing out nuclear power (seven units taken offline in March 2011, and a scheduled phase-out of the remaining nine plants between 2015 and

4. Energie-Wende: Wachstum und Wohlstand ohne Erdöl und Uran." Fischer S. Verlag GmbH. Frankfurt am Main.
5. Gesetz über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz (Stromeinspeisungsgesetz) v. 7.12.1990 (StrEG), BGBl. I S. 2633, see Theobald, et al. (2013, p. 495).

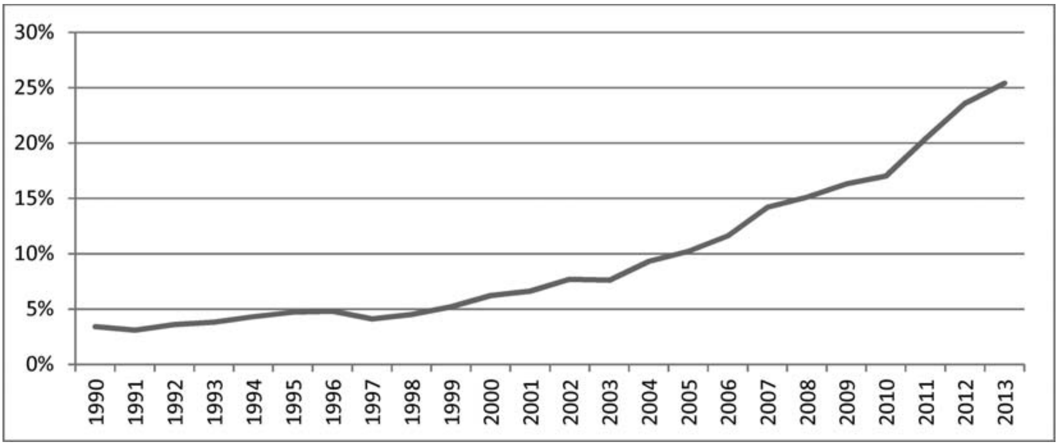

FIGURE 1

Share of renewables in German electricity generation (1990–2013)

Source: Federal Ministry for Economic Affairs and Energy

2022); increasing the share of renewables for electricity generation to at least 38% in 2020, 50% in 2030, 67% in 2040, and 80% in 2050 and the share of renewables in final energy consumption to 30% by 2030 and above 60% in 2050; reducing greenhouse gas emissions, compared to the 1990 levels, by 40% in 2020, 55% in 2030, 70% in 2040, and 80–95% in 2050; and setting ambitious targets for energy efficiency.

In addition, the energiewende also includes a new paradigm of energy policy, combining "big energy" companies with a large share of decentral generation owned by individuals and cooperatives. Though this objective is not written in any law, it forms the basis of the public consensus, and eventually assures the longer-term success of the energiewende.

A MID-TERM ASSESSMENT OF THE ENERGIEWENDE

Quantitative objectives are attained

At the time of this writing, the energiewende has achieved some of its interim objectives.[6] The March 2011 moratorium on Germany's seven oldest nuclear plants has had little effect (see Kunz and Weigt, 2014, in this issue) and the gradual phase-out of nuclear will continue through 2022. With respect to renewable deployment, the energiewende is on track, too. Several updates of the EEG (2005, 2009, 2012) have not changed the philosophy of the renewables policy within the energiewende, i.e. a fine differentiation by technology, by site, by size, and by other criteria (see Leuthold and Weigt, 2009, and Theobald and Theobald, 2013). Feed-in tariffs were gradually reduced, more or less corresponding with cost reductions in renewable electricity. Most significant, in 2013 Germany broke the threshold of 25% renewable energy consumption (see Figure 1).

One of the main drivers of the energiewende is to prove that ambitious climate targets are compatible with energy supply security. The German government has set GHG emission

6. For a regular survey of results refer to the governmental reports, e.g. BMWi (2014). „Second Monitoring Report "Energy of the future".

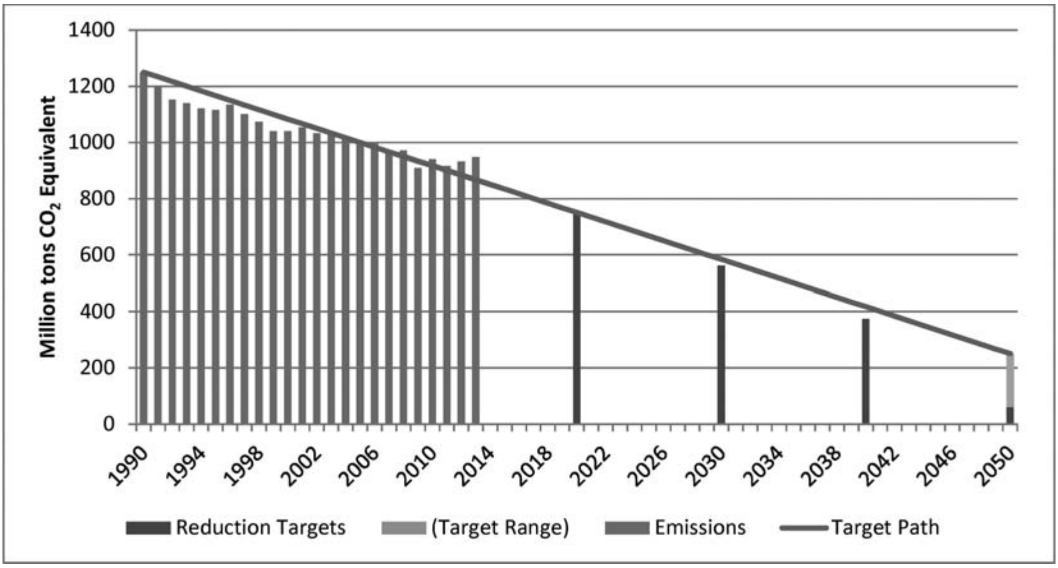

FIGURE 2
Greenhouse gas emissions in Germany: historical path and future trajectory to 2050
Source: Umweltbundesamt

reduction targets that are beyond those agreed at the European level (e.g., 20% reduction by 2020, and most likely 40% reduction by 2030; basis: 1990), which are forerunners of climate policy in the international context. Figure 2 shows that Germany is almost on track to reach its targets. Between 1990 and 2011, a reduction of over 25% was achieved, which corresponds with the 2020 target (-40%). Due to the collapse of the European Union CO_2-trading price, which has fallen from an average € 20/t to below € 5/t., there is now a slight increase of CO_2 emissions. However, the German government has confirmed its determination to reach its targets for 2020, and this year it is developing a Climate Action Plan to identify low-cost measures to stay on track. A long-term Climate Action Plan now in preparation will translate the longer-term targets into concrete policy.

. . . without challenging energy system security

The Energiewende will only be successful if costs can be contained, and if it does not put supply security in danger. Traditionally, the German electricity system is run using high security margins, both with regard to ample generation oversupply, and sufficient network capacities ("copperplate"). Should either suffer, the energiewende effort will be imperilled. Preliminary evidence however suggests that neither resource adequacy nor network stability have been adversely affected by the energiewende thus far. Kunz and Weigt (in this issue) show that even the nuclear phase-out to be completed in 2022 will not lead to undersupply, provided that some backup capacity is contracted with neighboring countries (Austria and Switzerland), and that the regulator's (BNetzA) conservative approach is maintained. Presently, there seems to be no need for a capacity market, and that the strategic reserve implemented in 2011 will suffice (Neuhoff, et al., 2014).

Analyses of network security show that Germany's transmission network including connections to its neighbors, is sufficiently developed to absorb the rising share of renewables (Gerbaulet et al. 2013, Egerer et al. 2013). Until today, network congestion was not an issue, less than 0.5% of all electricity consumed needed to be redispatched. Contrary to public opinion, network extension is proceeding smoothly, and some missing connections between East and West Germany have been filled. The high-voltage direct current (HVDC) connection planned between the North Sea and South Germany will ensure additional flexibility (Kunz et al., 2013).

. . . neither increasing the social costs

Any reform process has ultimately to undergo a cost-benefit analysis of some sort, in order to obtain some insights into the overall economic effects. A major criticism of the energiewende is its high costs. Indeed, introducing renewables with high capital costs is an expensive undertaking, in particular in phase I of the energiewende, when specific costs were still quite high. However, a dynamic analysis suggests a comparative advantage of renewables, as they enter cost degressions. Also, an approach in terms of social costs, i.e. taking into account externalities, such as environmental degradation or risks of nuclear accidents leads to the conclusion that the energiewende is socially efficient.

The simplest analysis compares the *social* costs of the three pillars of the old electricity system: nuclear, coal, and renewables. It now appears that nuclear is the most expensive of all electricity sources, in particular when taking a social perspective, i.e. accounting for all types of costs. With respect to levelized cost of electricity, Toke (2012)[7] and Broccard (2014)[8] have indicated that nuclear has no more cost advantage over other electricity generation, in particular due to its high capital costs;[9] the capital costs of nuclear power plants have continuously risen since the 1970s; ongoing projects are likely to be above € 6.000/kW.[10] In addition, the huge costs incurred in R&D and the development of new reactors are all being paid by the public sector. In addition, the cost of disposing spent fuel is still largely unknown, because even after six decades of nuclear energy use, there are no permanent disposal sites anywhere in the world that guarantee the safe storage of nuclear fuel rods for tens of thousands of years. Another important cost factor is insurance against potential major accidents. The high costs of major accidents at nuclear power plants are difficult to quantify; currently, these costs are borne primarily by society, because nuclear power plant operators are subject to very few insurance obligations. Irrespective of the most economically advantageous form of insurance (public, private, or a mix), the costs must be included in the cost-benefit analysis. The economic viability of nuclear power will also be diminished by a further tightening of the safety regulations currently being developed at the pan-European level.[11]

7. Toke (2012): Nuclear Power: How Competitive is it Under Electricity Market Reform? Presentation given at the HEEDnet Seminar, London, 17.07.2012.

8. Broccard (2014): The cost of nuclear electricity: France after Fukushima, Energy Policy, 66: 450–61.

9. Broccard (2014) concludes "the future cost of nuclear power in France to be at least 76 €/MWh and possibly 117 €/MWh. A comparison with the US confirms that French nuclear electricity nevertheless remains cheaper. Comparisons with coal, natural gas and wind power are carried out to the advantage of these."

10. Hirschhausen and Reitz (2014): „Atomkraft: Auslaufmodell mit ungelöster Endlagerfrage". DIW Wochenbericht 13.2014.

11. After the Fukushima nuclear accident, EU Energy Commissioner Günther Oettinger recommended mandatory stress testing of European nuclear power plants. The results pointed to the urgent need for retrofits at some plants. A draft regulation will form the basis for the binding rules on liability and compulsory inspection routines to be introduced in all countries. See European Commission, Draft proposal for a Directive amending Nuclear Safety Directive IP/13/532, June 13, 2013. Francois Lévèque (2013, Nucléarie On/Off. Paris, Dunod, p. 171) provides the most intuitive explanation why the civil use of nuclear power can not be considered as economic: "Nuclear power is the child of science and war" („L`énergie atomique est fille de science et de la guerre.), own translation.

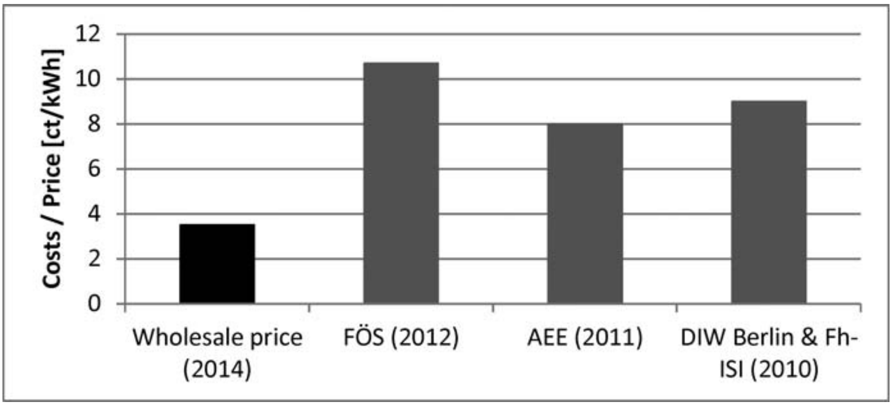

FIGURE 3

External costs of lignite and the current electricity price in Germany

Source: Own depiction. Küchler and Meyer (2012): "Was Strom wirklich kostet". Forum Ökologisch-Soziale Marktwirtschaft; Mühlenhoff (2011), Agentur für Erneuerbare Energien, and Breitschopf and Diekmann (2010) "Vermeidung externer Kosten durch Erneuerbare Energien—Methodischer Ansatz und Schätzung für 2009.

The next cost factor is the social costs of the electrification of coal. These include the greenhouse gas externalities, the effects of sulphurdioxides (SO_2), nitrogen oxides (NO_x), fine dust particles, mercury (Hg), and groundwater contamination. Local negative externalities include dust and noise, as well as the displacement of people for the opening of new lignite mines. Estimates for the social costs of lignite, the most CO_2-intensive fuel, are in the range of € 80–120/MWh, or about twice to three times the current wholesale price of electricity (see Figure 3). Given that system-wide carbon capture, transport, and sequestration (CCTS) is unlikely, there is no economic perspective for coal. Some countries have adapted instruments for a structured phase-out, such as emission performance standards (EPS).

On the other hand, given the ongoing innovations in solar photovoltaic and wind power technologies, further decreases in specific production costs and significant learning potential can be expected for these two renewables on the 2050 horizon. In fact, the most spectacular cost degression is that of photovoltaics. Some studies indicate that learning rates over the last few years have remained stable at 15–20%, i.e. that the specific costs fall by 15–20% when installed capacity doubles; this trend is expected to continue for the foreseeable future.[12] Capital costs have fallen from € 4,000/kW a decade ago to below € 1,000/kW, further reductions below € 500/kW are expected (Schroeder, et al., 2013, see Figure 4). Solar is now approaching "grid parity", i.e. the similar level of costs as conventional sources (ignoring externalities). Onshore wind turbines, too, have realized both significant production increases and cost reductions in recent years. Different studies identify learning rates ranging from 5-15%, although they are likely to decline over time (Pahle, et al. 2013). Experiments with different turbine installations show that it is possible to decrease the average production costs of wind power when using optimized turbine designs, even when the specific investment costs

12. Pahle et al. (2012) and Schröder et al. (2013).

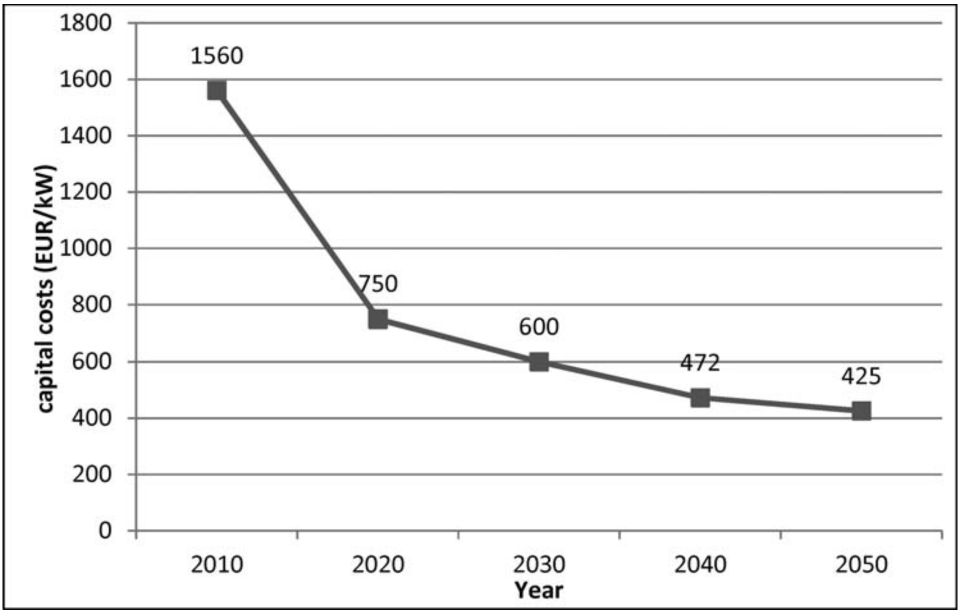

FIGURE 4
Capital cost of solar photovoltaics, 2010–2050
Source: Schroeder et al. (2013)

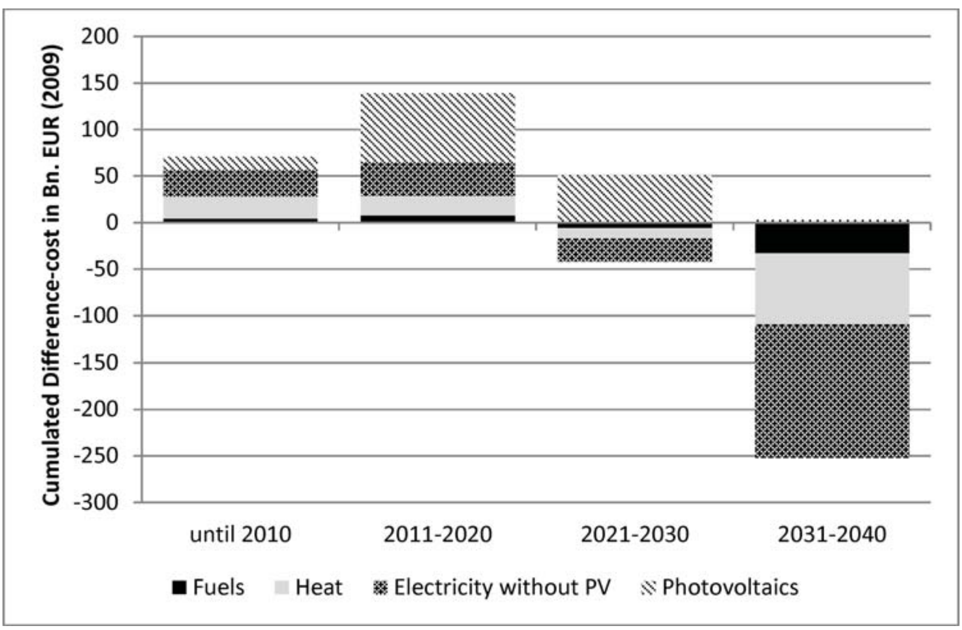

FIGURE 5
Comparison of the costs of the energiewende, compared to a business-as-usual case
Source: DLR, Fraunhofer IWES, IFNE (2012). “Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global“. Berlin.

remain constant.[13] Agora (2013) shows that the levelized system costs of renewables have already reached those of hard coal and gas power plants, in the range of € 7–9 cents/kWh, to which the system costs for backup capacity have to be added. But considering the high negative externalities of coal, the even higher social costs of nuclear plants, and the expected cost reductions of renewables, it is plausible to view the energiewende as a socially efficient project.

A cost analysis of the government puts forward future system costs of a renewables-based power system, and compares these with the business-as-usual (BAU) case. Under certain assumptions on fuel costs and capital costs of renewables, an inverse J-shaped curve for the "difference costs" is obtained by the Ministry of the Environment (see Figure 5). While the ambitious renewables targets are costly, in the first phase, particularly for solar between 2011–2012, the sign of the differences reverses around 2025, and total energy system costs are significantly lower than in the BAU case (by about € 250 bn.) after 2031. This cost analysis also suggests that the energiewende is an investment with high returns.

POSITIONING OF THE PAPERS FOR THE SPECIAL SECTION

Nuclear phase-out: little effects on the electricity market

A controversial political debate about the energiewende focussed on the role of nuclear power in the German energy system. It is therefore surprising how small the effects of the nuclear moratorium declared after Fukushima (March 2011) were. Friedrich Kunz and Hannes Weigt (2011) were among the first academics to publish a model-based study on the moratorium, in June 2011, and they revisit their own and other research: "Germany's Nuclear Phase Out - A Survey of the Impact in 2011 and Outlook to 2022," examines the past three years with the benefit of hindsight (Kunz and Weigt, 2014).

They find that closing 6 GW of nuclear capacity in 2011 had little effect on the German and European wholesale electricity markets, because ample capacity was available to compensate. Wholesale electricity prices slightly increased by € 2–3/MWh, whereas the German net export surplus slightly reduced, only to realize a 34 TWh record surplus in 2013. The authors look forward to 2022, when the last remaining reactors will close. Given the conservative approach of the network operators and the regulator, the authors argue that no shortage is to be feared, not even in South Germany, where most of the plant closures will occur. From a political perspective, the phase-out has become irreversible: political resistance by the nuclear energy industry has abated, except for deciding who is to pay the high costs of decommissioning and final storage of 30,000 m^3 of radioactive waste.

Investment scenarios for the energiewende: storage, backup capacities, transmission lines

With the nuclear phase-out being resolved, and the end of coal plants in sight, the focus of energy analysis shifts to the structure of a renewables based power system, and the necessary investments related hereto. In "Power system transformation towards renewables: investment scenarios for Germany," Jonas Egerer and Wolf-Peter Schill (2014) deploy an integrated modeling approach to show the diversity of options available to design a renewables-based energy

13. Adapting the design of the generator, rotor length, and mast height to locally prevailing wind conditions realizes significant gains in yield. A lower specific capacity installation can lead to lower specific power generation costs. J.P. Molly, "Design of Wind Turbines and storage: A Question of System Optimisation". *DEWI Magazin*, no. 40 (February 2012): 23–29.

system. They find that investments in gas-fired power plants, pumped storage, and more HVDC transmission can be substituted against each other, and that "a little bit of all" is required for system stability. They suggest that gas plants are mainly needed in South Germany, and creating some investment incentives that do not exist under Germany's present corporate requirements. Pumped storage, while modest today, could provide additional benefits such as the provision of reserves and other ancillary services. They also suggest a few more transmission lines to facilitate the regional exchange of electricity in cases of surpluses and deficits.

German energiewende in the regional and European context

We have not mentioned the European context much so far, yet the German energiewende is taking place in the midst of the emergence of a single European market. It comes logical, therefore, that in this last paper of the Special Section, emphasis is placed on the regional context of the energiewende, and even more broadly, on regional cooperation patterns in the European context at large. In fact, the traditional debate was very much focussed on the dichotomy between *national* and *European-wide* approaches. However, as electricity sector reform is proceeding, the *regional* level, i.e. neighbouring countries or groups of countries, is emerging as the real powerhouse of reforms (see Jong and Egenhofer, 2014). A particularly striking example is the cooperation amongst the Nordic countries of Scandinavia, that has set benchmarks for the rest of Europe; however, other regions are trying to follow suit, such as the the Pentalateral Forum, the North Sea Countries Offshore Grid Initiative and the Baltic Energy Market Interconnection Plan.

Clemens Gerbaulet, Casimir Lorenz, Julia Rechlitz, and Tim Hainbach (2014) analyze "Regional cooperation potentials in the European context." The authors first discuss the Pentalateral Forum, the North Sea Countries Offshore Grid Initiative and the Baltic Energy Market Interconnection Plan and then focus on the potential for cooperation in the Alpine Region (France, Germany, Switzerland, Austria, and Italy). They believe that cross-border cooperation is possible even when involving only the operation of existing assets, and that the necessary capital-intensive investments in generation, renewables, and transmission, while challenging, can also benefit the participating countries. They conclude that expanded regional cooperation is an essential element of both European decarbonization and German energiewende initiatives.

CONCLUSIONS

The low-carbon energy system transformation in Germany is focussing on the installation of renewable energies, and the phase-out of both nuclear and coal electrification. Based on a public discussion going back to the 1970s, the specific circumstances of 2010/2011 have led to public policy decisions with a broad public support, which now is commonly called "energiewende". In this introductory paper, we have sketched out the major trends of the energiewende, and also indicated that four years into the process, reforms are proceeding steadily, and are more or less on track with the goals: the share of electricity from renewables is approaching 30%, the nuclear phase-out is on track to the last plant closure in 2020, and the greenhouse gas reduction objectives (e.g. 40% to 2020) have been confirmed by the new government without hesitations. Political and public support for the energiewende continues. Naturally, there will always be political and policy debates about the optimal ways to attain the objectives of phase 2. Yet there is no doubting that the energiewende is and will be a major social and environmental project in the coming decades.

The challenges for the near future will be to contain the costs of the energiewende, and to anchor it in the European context. Back-of-the-envelope calculations indicate that the energiewende is socially efficient, because it phases out two energy sources with high social costs (nuclear and coal), and that the future system costs are lower than in the business-as-usual case. However, the regulatory framework will determine the real costs of the renewables integration, and discussions are currently underway on the appropriate market design. Also, the need to coordinate the energiewende both with neighbours and in the European context, is evident: after the nuclear phase-out decision taken unilaterally, this need for coordination is now widely acknowledged by the public authorities, and imposed rigorously by the European Commission. This paper suggests that the first phase of the energiewende has been a success and has laid the groundwork for the second phase, but significant reforms are still outstanding.

ACKNOWLEDGMENTS

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