Germany's Energy Transition and the European Electricity Market: Mutually Beneficial?

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Abstract: Germany's energy system is in transition towards less nuclear, lower carbon emissions and more renewables. Notwithstanding widespread neglect of its European dimension, this *Energiewende* will further exacerbate current network fluctuations due to the significant increase in wind and solar power. Key data from Denmark show that this transition will soon bring the German national power system to its limits for absorbing the resulting intermittency, and increase the need for more cross-border power transfers. Yet network analysis of import/export data shows that Germany's position in the European power system is contrary to the Danish case. The need for a European solution for Germany's energy transition will therefore soon become evident. In order to establish the necessary infrastructure, the *Energiewende* needs hence to be guided by an economic approach designed to prevent further fractures in the Internal Electricity Market. Constructive negotiations with neighbouring countries on market designs and price signals will be important preconditions. The article emphasizes the still neglected European paradox of Germany's energy transition and presents working examples and possible solutions to uphold electricity supply in Europe's power house.

Key words: Germany, energy system, energy exchange, power grids, power distribution, power distribution faults.

1. Introduction

The neglect of Europe's Internal Electricity Market is one of the most surprising aspects of Germany's *Energiewende* (energy transition—Substantially increasing the share of renewables in the energy mix, while phasing out nuclear power), as the country's central geographic position, its importance in the European electricity system and the growing pressure on Europe's networks makes a European approach imperative: A dense, cross-border infrastructure which allows flexible import and export of electricity from one region to the other might be the *sine qua non* of Germany's *Energiewende*, at least from a technical standpoint. The German government's decision to initialise a complex transition of the country's energy system therefore could be followed by a turn in its policy towards market opening. Germany might be

forced to give up its longstanding opposition against deeper integration and become an advocate of an European power system which is large and flexible enough to allow trade and load management at different levels—Local, national, and supranational.

Yet this scenario has an economic flipside, which is much less straightforward: As the European Internal Electricity Market is still characterized by a variety of national (and regional) market models, its features, among other things, different electricity tariffs. Given that potential exporters of electricity should favour international markets and better transnational interconnectivity, electricity producers that might sustain losses in their market share, should oppose it. The delicate task of market opening hence depends on mutually beneficial interactions between Germany's energy transition with its environment in a truly finalised Internal Electricity Market. Yet one key element of Germany's energy transition makes the outcomes of the *Energiewende* highly uncertain: The

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large scale integration of renewables into the network makes export and import dependent on the erratic forces of nature. It is therefore unclear who will be exporter, who importer in a mixed system, where nuclear and coal power on the one hand, wind and solar power on the other work in combination.

Two different concerns are at stake: in the wake of Germany's nuclear phase-out several nuclear power plants have been taken off from the grid, until 2022 the phase-out is to be complete. The loss in generation capacity would reach a stunning amount of 22% of Germany's electricity demand [1]. Since Germany has one of the highest electricity tariffs in Europe, the prospect of cheap coal and nuclear power imports seems to be the logical consequence of further market opening and very attractive for neighbouring countries, notably the Czech Republic, France and (prospectively) Poland. This prospect would put the German government in a very difficult position, since it contradicts the entire *Energiewende* concept. The electricity supply gap following the nuclear phase-out of 8 nuclear plants in 2011 seems to confirm this scenario: Czech and French nuclear power covered for the phased-out German capacities.

On the other hand the market value of German surplus wind energy tends towards zero during power generation peak hours, outdistancing even cheap French nuclear current. This in turn puts neighbouring countries in a difficult position, since more

cross-border power transmission capacities ultimately mean more export of German wind energy, which is highly unattractive for incumbents, national champions and governments alike. In this respect the comparison of national electricity and generation data before and after the nuclear phase-out does not suggest that Germany will become net importer—on the contrary: In 2012 Germany's generation exceeded its consumption by far, which indicates export of electricity (Fig. 1). Germany's energy revolution may hence turn out to be of little value for neighbouring countries. This paper attempts to evaluate the prospects of Germany's energy transition from a European perspective.

After a short outline of German energy policy and its paradoxical reciprocity with its European environment, the following paragraphs elaborate the implications of national policy to boost renewables for the European power system in more depth. Key data from Denmark show the close relationship between intermittent renewables on the one hand, and the need for supranational power systems to balance network fluctuations on the other: relatively small size, favourable position, and the necessary infrastructure enables this European country to maintain grid stability by switching flexibly between power export and import. Taking the geography of Europe into account, the Danish case therefore suggests that large numbers of wind and solar power on the national level imply deeper integration on the European level. Given the

Fig. 1 Ower generation and consumption in Germany 2010-2012 (Data: ENTSO-E).

absence of large storage facilities to balance its grid, Germany will therefore be forced to take a European solution for its power supply into consideration. Yet network analysis of import/export data from 2012 reveals the centrality of Germany in the European power system (Fig. 2). As neighbouring countries will increasingly be affected by erratic network fluctuations coming from the German system, intensive negotiations will be necessary in order to enable a European energy transition.

2. Energy Transition in Europe's Power House

The German government proclaimed its “revolution of Germany's energy sector” (Angela Merkel) without consulting its neighbours. Yet in Europe national power

Fig. 2 Mport/export of electricity in Europe 2012 (computer program: GEPHI; algorithm: ForceAtlas 2; knod size: eigenvector centrality; arrows: power flows (TWh); short arrows: deep integration; long arrows: little integration; colour: subgroups in the network; data source: ENTSO-E).

systems do not function in isolation from one another; cross-border power flows are daily routine. In addition, the Internal Electricity Market helped with the first steps of Germany's energy transition: interconnections with neighbouring systems not only enabled wind energy surpluses to be exported, but also allowed electricity imports to bridge the supply gap after the rapid phase-out of nuclear plants in the wake of the Fukushima disaster. Increasing the input of renewables hence not only subverts the hierarchical top-down logic of electricity distribution on the national level, but has implications for the supranational dimension as well [2].

The major blackout of November 2006 illustrated the transnational nature of Europe's power sector. Beginning in north-western Germany, the outage cascaded through Austria, Belgium, France, Italy, and Spain before finally crossing the Strait of Gibraltar to affect the Moroccan power system. Analogously, the repercussions of the *Energiewende* do not stop at Germany's borders and may turn out to be more far-reaching than originally intended. While the transition could stimulate the trend towards a more deeply integrated Internal Electricity Market and a more sustainable European power sector, the risk of disintegration of the European market and recourse to fossil fuels is equally present.

Both trends would ultimately result from the growing share of intermittent renewable energy sources such as wind and solar power. Depending on natural forces which are difficult to forecast and impossible to control, these forms of electricity generation cause growing fluctuations in the system and make it difficult to match output and consumption. Compared to past decades where baseload power generation defined the system, with power plants adapting their output to (predictable) shifts in demand, renewables turn the logic of power generation and distribution upside down. Nowadays, grid management must match fluctuating generation to power consumption. Such a system is never far from blackout (overcharge) and brownout (voltage drop), making

network management a Sisyphean challenge [3] (Fig. 3). Wind power fluctuations matching those of 7 nuclear power plants phased out in the months after Fukushima despite relatively small share of wind power in the system.

With regard to Germany's role as the main transit country for electricity in the centre of Europe, interactions with neighbouring systems have to be taken into account: irrespective of whether it is indeed a revolution or rather an evolutionary process, the country's energy transition amplifies the "ups" and "downs" in the network as intermittent renewables largely replace the phased-out nuclear power stations. In this context uncontrolled power flows of surplus German wind energy to neighboring countries indicate the limitations of national systems in meeting the challenge. But transmission capacities are scarce and already heavily congested. Hence, the *Energiewende* creates the need to adapt the European power transmission system. Cross-border electricity swaps will have to increase to keep the networks stable, since only a truly integrated Internal Electricity Market could provide the capacity needed for synergetic interaction of diverse national power systems. One of the main tasks of energy policy therefore is to advocate a power system which is flexible enough to fulfil several tasks at once, and at different levels—Local, national and supranational. The difficulties to bring enough units from Germany's cold reserve into operation point in a similar direction. Moreover, the ongoing discussions about which energy sources could provide climate-neutral and economic operating-load to counterbalance intermittent renewables show that the *Energiewende* could become a factor on international energy markets.

3. Best Practice in the North: Denmark's Grønne Omstilling

The Nordic electricity market is a "best practice" case of integrated electricity markets with high shares of renewables: a state-of-the-art transmission

infrastructure densely interconnects the national systems, making electricity a commodity which is traded across borders. Moreover, with 64.9% in Norway, 47.3% in Sweden, and 30.3% in Finland, the share of renewables in gross electrical consumption is well above the EU average [4]. Yet, with the exception of Denmark, these high numbers for renewables can not be compared to other EU member states due to the widespread availability of hydroelectric power in the Nordic countries. The Danish energy sector has otherwise been described as a microcosm of current major energy issues [5]. And with 19.9%, renewables in Denmark already exceed the German 18% target set by European Directive 2009/28/EC for the year 2020 (and are set to rise to 100% according to the Danish government) [6]. These high numbers are primarily based on electricity generation (see below) and have to be seen against the backdrop of external shocks and a successful energy saving programme. In contrast to other European countries, Denmark never put its plans for a large nuclear sector into operation and phased out its world-leading nuclear research programme in the aftermath of the 1970s oil crisis. In the long run, the Danes gave high priority to energy efficiency and renewable energy.

Starting from a very low level of 1.8% in 1973 [7], renewables grew steadily to today's 29.1% of Denmark's gross electricity consumption [8], despite GNP growth of about 50% since 1980. Because Denmark became the EU member state with the lowest energy intensity and world leader in energy efficiency, the country's energy consumption remained stable over this period. Hence, the transformation of Denmark's energy system did not have to keep pace with economic growth. Wind power plays a role similar to the *Energiewende* concept, with wind turbines generating about 20% of the country's electricity demand [9] (Germany: 6% as of 2010 [10]). Given the absence of major storage capabilities due to geological conditions in Denmark, the success of Danish energy policy is striking.

Fig. 3 Wind/nuclear power generation in Germany 2010-2012 (Data: ENTSO-E).

Fig. 4 Power generation and consumption in Denmark 2010-2012 (Data: ENTSO-E).

3.1 Best Practice 1: Storage and Interconnections

Denmark's energy system has undergone radical change since the 1970s and is today one of the world's most decentralized. This structure imposes particularly high requirements on the national power grid. With regard to intermittency, interconnections with neighbouring countries play a major role. Whenever there is too much electricity from Danish wind farms, the energy can be discharged to pumped-storage stations to the north (Norway, Sweden), or to consumption centres to the south (Germany, Netherlands—see Fig. 4). Since the surrounding power systems are much larger, Danish power is insignificant and can be absorbed.

Conversely Denmark can rely on power (re-) imports. Denmark's superb interconnections with

neighbouring countries can therefore be considered to be the backbone of the country's energy system. Without that infrastructure the integration of wind power would hardly be possible [11]. Hourly alternation from energy import to export thus keeps the Danish energy system stable despite the country's large and growing proportion of intermittent renewables. The energy from wind power actually consumed in Denmark thus ultimately accounts for only the less striking average of 12 per cent of total electricity generated [11]. Connecting electricity generation to local heating systems is another way to discharge parts the wind power surplus. During peak hours, electric heaters replace fossil fuel combustion for the production of hot water, which is storable for many hours in pipes and tanks. With 62% of Danish

households connected to district heating the system has huge thermal storage capabilities for energy from Danish wind farms.

3.2 Best Practice 2: Operating Load and Biomass

High shares of intermittent renewables in the energy system require power stations to provide the network's base load, yet flexible enough to counterbalance the fluctuations in the system. After phasing out its nuclear programme Denmark switched to coal as the prime conventional energy source for network stabilization. But in recent years gas and biomass have become more important, whereas coal combustion is to be phased out by 2030 according to the Danish government's latest plans [12]. Biomass is slated to become the most significant climate-neutral energy source to reduce coal consumption [12].

Accordingly, biomass already accounts for approximately 14% of Denmark's energy consumption [13]. In the electricity sector the growing use of biomass dates back to the biomass agreement of 1993, which forces power stations to include biomass in their fuel mix. Biomass already exceeds 10 per cent of electricity generation [14]. Since this energy source can be used in the "co-firing" process, modern Danish power stations like Avdedøre near Copenhagen burn coal together with a mix of gas, wood and straw. Hence, no new power stations had to be constructed, as existing ones needed only marginal modifications. But Denmark's biomass resources are limited, and large amounts of the fuel therefore have to be imported [15].

4. Germany's Energiewende: Avant-garde of a European Energy System?

For 2020, the government in Copenhagen is seeking to cover 50% of electricity consumption using wind power, and this share is supposed to increase further until 2035 [16]. However, the example of Denmark's grønne omstilling shows that such developments do not take place in a vacuum, but encounter and interact with the European context. Integrating large volumes of

intermittent renewables into the Danish energy system would not work without interdependent electricity markets. Accordingly, Denmark's grønne omstilling and world leadership in the manufacturing of wind turbines have led to greater, rather than less, interdependency with countries to the north over the years. Two elements are decisive: the availability of suitable technical infrastructure and a legal framework that allows (short-term) trading in liberal transnational electricity markets. Being a member of the Nordic electricity market, which integrates Norway, Sweden, Finland and Denmark (with the Netherlands and Germany in its orbit), Denmark offered excellent energy policy conditions. Likewise, the German energy transition has a transnational dimension, but compared to the Nordic market it encounters a less developed European framework. Whereas the Nordic power market is fully integrated and based on an appropriate infrastructure, power systems and energy markets in the rest of Europe remain largely nationally defined. German surplus wind energy therefore flows randomly to neighbouring countries, causing technical, economic and political difficulties.

In the coming years this option will no longer be available since Germany's neighbours consider limiting such imports. Moreover, they themselves will be producing power surpluses from renewables according to national action plans [17] and projections [18]. Europeans will therefore be compelled to distribute electricity more efficiently [19] since network balance is considered to be in jeopardy if intermittent renewables exceed 5% in the power system. Yet in 2010 they already amounted to 5.6% of electricity consumed in the EU-27 (compared to 2.6% in 2005) and will rise to 17.1% by 2020, according to national renewable energy action plans [18]. The latest initiative of the European Commission to overcome deficits in the European power grid therefore includes not only trans-border power transmission and distribution networks, (cross-border transport of electricity to consumers on high-, medium- and

low-voltage systems) but also high- and extra-high-voltage transmission (“electrical highways”) [20]. The north sea countries offshore grid initiative, as well as single projects as the Kriegers Flak wind farm in the Baltic Sea which is designed for simultaneous use by Denmark and Germany, point in this direction and could form the nucleus of a European overlay network or supergrid. The inclusion of Norway suggests that such a network would be pan-European. In this respect it is noteworthy that the integration of the North African and European grids has already reached an advanced stage.

Member states are slow to adopt European legislation to deepen the integration of electricity markets. Yet Germany's energy transition appears to be the avant-garde of a developing European energy policy: with an overall target of 34.5% renewables in the EU's gross final electricity consumption in 2020 [18], EU policy corresponds almost exactly to German policy, which aims for 35% [21]. In the light of the Danish experience, the German targets could end up being exceeded, since the integration of large volumes of intermittent renewables requires large-scale electricity markets to absorb the “ups” and “downs” in the energy system. The Energiewende could therefore force Germany to support a policy of deeper integration of electricity markets in the EU and beyond.

5. Operating Load and Biomass from a European Perspective

The internal electricity market helped to implement the first steps of Germany's transition. Interconnections with neighbouring countries not only enabled wind energy surpluses to be discharged, but also permitted electricity imports to bridge the supply gap after the quick phase out of nuclear plants in the wake of the Fukushima disaster. But transmission capacities are scarce and already heavily congested. The deployment of large volumes of intermittent renewables therefore increases the urgency of creating new power transmission infrastructure in Europe. But

in a complete internal electricity market where an adequate capacity for transmission of generated current exists, which side of the border these power plants are located is irrelevant; it can be expected that electricity will be generated in those plants that have the lowest marginal costs. In the course of its energy transition Germany resorted to its “cold reserve” of fossil fuel plants to provide a stable electricity supply [22]. Hence, the Energiewende might lead not only to growth in renewables, but oddly enough might also augment the current trend in Europe, since 2009 [23], of using (cheap) coal [24-27].

But not every technology based on renewable energy exhibits large fluctuations in output. On the contrary, biomass, hydro and geothermal energy are stable in its electricity output and capable of providing the necessary operating load to counterbalance wind and solar power. But since continental Europe lacks sufficient hydro potential, only the combustion of carbon can fulfil the task of counterbalancing the fluctuations caused by wind and solar power. If recourse to large-scale use of coal in the internal electricity market is to be avoided, alternatives must be found that can compete with its price levels. In this respect, it is noteworthy that the first signs of an international biomass market are emerging [28, 29]. Based on new technologies such as pelletization, briquetting and torrefaction, wood biomass such as forest residues becomes a cost-effective alternative [30] for co-firing in coal power plants [31]. The European Union therefore aims to develop its own supply chains [32]. Due to lower wages the new EU member states, especially the Baltic countries, have big potential in this respect [33, 28].

6. Prospects

Denmark's green energy transition, or grønne omstilling, began in the aftermath of the 1970s oil crisis, and shows that “green transition” is a long-term project. But successful energy-saving policies to decouple economic growth and electricity

consumption can help to speed up the process: with stable energy consumption, the deployment of renewables does not have to keep pace with movements in the gross domestic product. Denmark's green transition also reveals the limitations of national systems for absorbing large volumes of intermittent renewables and the need for transnational infrastructure and markets to ease the pressure on the grid by cross-border power transfers. Yet transmission capacity is still scarce and heavily congested in Europe [19, 31, 34] and with differing electricity tariffs and market models an active policy of market opening is still a delicate task [35, 16]. All the more so in the case of the Energiewende, deeper integration and growing numbers of renewables will inevitably bring new dynamics to electricity markets in Europe.

7. Conclusions

A share of approximately 5% intermittent renewables in the power system is regarded as critical for network stability [36]. With growing feed-in from decentralized and intermittent sources like wind and photovoltaic, the risks of grid outage increase, therefore making the construction of new power lines imperative to maintain grid stability. Their share in the EU exceeded that margin in 2010, and will increase further according to the Energy Roadmap 2050 [37]. Depending on the underlying scenario, between 25% and 65% of the EU's electricity consumption will be supplied by this form of energy by 2050. Germany's energy transition accelerates this process, since the nuclear phase-out increases the need for new generation capacity, and renewables, especially wind power, will have to take the place of decommissioned plants according to government plans. This energy transition therefore increases the pressure on Europe's electricity networks and makes the inclusion of neighbouring countries in the planning of Germany's energy system an imperative and might be the missing cornerstone in the German transition process, offering untapped potential for an European Energiewende.

The successful transformation of Germany's energy sector therefore depends on a mutually beneficial model: in order to set up an infrastructure which allows a comfortable matching of power production and consumption in Europe, the Energiewende should be guided by an economic approach designed to overcome, not deepen the fractures in the Internal Electricity Market. Yet electricity tariffs in Germany are already above the European average, both for private households and for industrial consumers (Figs. 5 and 6). Limiting tariffs is therefore the crux of Germany's energy transition. Backup power generation using coal

Fig. 5 Electricity tariffs 2011, private households.

Fig. 6 Electricity tariffs 2011, industrial consumer.

and second-generation biomass in combined combustion to counterbalance wind and solar power could keep costs down and allow further market opening. Moreover, effective negotiations with neighbouring countries to match market designs and price levels and develop common infrastructure projects are important elements for making Germany's energy transition work.

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