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Published in:
Bundesnetzagentur: Tagungsband wissenschaftsdialog 2016

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

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Experience with Grid Expansion in a Northern European Perspective

Stephanie Ropenus

Stephanie Ropenus joined Agora Energiewende as a Senior Associate in June 2014. Her focus is on grid integration of renewable energy sources and on energy policy in the Nordic countries. Prior to that, she worked as a policy advisor (grid integration) and deputy policy director at the German Wind Energy Association. Earlier, Stephanie Ropenus spent eight years in Denmark. She worked as a scientist in the field of energy economics at Risø National Laboratory for Sustainable Energy, Technical University of Denmark (today DTU) in Roskilde. Stephanie Ropenus took her PhD in economics on „Distributed Generation in European Electricity Markets - Current Challenges and Future Opportunities“ (Risø DTU in cooperation with the University of Southern Denmark). She received an M.Sc. in EU Business and Law from the Aarhus School of Business.

Abstract

The power grid constitutes an essential flexibility option for integrating ever-greater shares of variable renewable energy, such as wind power and solar photovoltaics. The development of interconnectors between neighboring EU Member States enables cross-border balancing. The potential for trade results from the differences in hourly wholesale electricity prices between regions or countries. The presentation given by Stephanie Ropenus at the 4. BNetzA Meets Science Dialogue provides some insights into increased integration of European electricity markets from a Nordic-German perspective. In doing so, it draws on the results of three reports commissioned by Agora Energiewende where Stephanie Ropenus acted as project leader, [1], [14] and [15], or co-author [2]. Increased integration between the Nordic countries and Germany will become ever more important as the share of renewables increases. Denmark is a prime example of how great interconnectivity can enable the integration of high wind energy shares into the power system. To some extent the Nordic electricity system can be considered unique with its complimentary power generation mix of wind energy in Denmark and hydropower as a "green battery" in Norway and Sweden. In general, closer integration of the Nordic and German power systems leads to better utilization of renewable energy and induces price convergence between the two regions on the wholesale electricity market. While the overall welfare effects of increased integration are positive, there may be significant distributional effects across stakeholder groups (power producers and consumers) within countries. These effects need to be taken into account for creating public acceptance for new lines and for the cross-border allocation of network investments.

Primary publications

Ea Energy Analysis (2015). The Danish Experience with Integrating Variable Renewable Energy. Study on behalf of Agora Energiewende. [1]

Agora Energiewende and DTU Management Engineering (2015). A Snapshot of the Danish Energy Transition. Objectives, Markets, Grid, Support Schemes and Acceptance. [2]

Ea Energy Analysis, DTU and DIW (2015a). Increased Integration of the Nordic and German Electricity Systems. Modelling and Assessment of Economic and Climate Effects of Enhanced Electrical Interconnection and the Additional Deployment of Renewable Energies (Full Version). [14]

Ea Energy Analysis, DTU and DIW (2015b). Increased Integration of the Nordic and German Electricity Systems. Summary of Findings. Study on behalf of Agora Energiewende and Global Utmaning. [15]

Introduction

The power systems in the Nordic countries and Germany are characterized by increasing shares of electricity based on renewable energy sources (RES-E). Germany is striving for a 55 to 60 percent share of renewables in electricity consumption by 2035. Denmark aims at becoming independent from fossil fuels in all energy sectors, including electricity, heating and transport, by 2050. In addition to already existing hydropower reservoirs, Norway, Sweden and Finland, have large untapped potentials of wind energy. Increased integration between the Nordic countries and Germany will bring mutual benefits for integrating higher RES-E shares into power systems. At the same, an increase in cross-border transmission capacities is one of the prerequisites for the completion of the European internal energy market. This presentation/paper briefly provides some insights into experience with grid expansion from a European perspective based on Nordic-German electricity market integration. The remainder of this paper is organized as follows: Section 2 focuses on the example of Denmark. It illustrates how interconnectors can become an important flexibility option for integrating high shares of wind energy from a country perspective. Section 2 is partially based on reports [1] and [2] that look into the Danish energy transition, including the Danish experience with integrating variable renewable energy, notably wind energy. Section 3 provides a brief overview of a study on increased integration of the Nordic and German Electricity systems [14][15]. The study assessed and discussed the economic and climate effects of further integrating the Nordic and German power systems.

The grid and cross-border exchange as a flexibility option from a country perspective – the example of Denmark[1]

A brief overview of the Danish electricity system

Denmark is a pioneer not only in the deployment of wind power, but also in implementing a green energy transition across all sectors. Until 2050 Denmark aims at becoming independent from fossil fuels in electricity, heating and transport. The Danish energy strategy [3] is comprised of two main pillars: firstly, an increase in renewable energy sources in the electricity, heating and transport sectors, and, secondly, energy efficiency measures. A large portion of the country's future electricity – and energy – demand will be met by wind power. The Energy Agreement of 2012 stipulates that wind energy will contribute to half of Danish power consumption by 2020 [4]. In 2015 a new world record was reached with wind energy supplying 42.1 percent of Danish electricity demand [5]. The Danish power system has been undergoing a transformation, from a highly centralized to a more dispersed structure in electricity generation. In the 1980s the Danish electricity mix was dominated by large-scale, central thermal power plants. Over the years, there has been increasing deployment of decentralized combined heat and power (CHP) plants as well as wind turbines. Simultaneously, the share of coal has been decreasing even though it is still the dominant fuel in Danish central and decentralized power stations. More than 60 percent of thermal power production[2] is based on CHP (located at 16 central production sites and around 1,000 decentralized CHP, industrial and local plants). The year 2015 was an outlier: there were high net imports of electricity from neighboring countries, an increase in wind power, and 79.1 percent of thermal electricity generation was produced in combination with heat [6]. Apart from wind energy, biomass constitutes an important renewable energy source. In 2015 biomass and biogas contributed to 25 percent as a primary fuel source in CHP plants (energy content). By 2025, an increase in biofuels (biomass and biogas) is expected to provide up to 50 percent of total electricity and CHP production in Danish power stations [7].

Challenges to the integration of wind power and the role of interconnectors[3]

There are three major challenges associated with integrating high shares of wind power.

Challenge 1: To ensure that wind power remains valuable when it is very windy.

Wind energy produces electricity depending on the weather situation. In times of high wind energy feed-in, the larger wind share moves the merit order curve to the right, which consequently results in lower wholesale electricity prices. The downward pressure on prices induced by high wind energy feed-in exerts economic pressure on conventional power plants. Because the latter are run fewer hours, they have less time in which to recover their investments [1]. In the

1 This section is partially based on [1] and [2]; figures and numbers in the brief overview have been updated with latest data available.

2 This excludes electricity generation based on wind energy, solar PV or hydropower.

3 Portions of this section are extracted from [1].

future, renewable power producers will also feel this pressure [2].[4] One major challenge lies in ensuring that wind power remains valuable when it is very windy, both to maintain its socio-economic value and in order to preserve the basis for continued wind power deployment. This necessitates the use of flexibility options within the entire system. One important flexibility option is exporting electricity to neighboring countries. The case for trade results from hourly price differences between Denmark and its neighbors. Nordic hydropower stations can function as cheap and effective energy storage for wind power [1].

Challenge 2: Ensuring sufficient generation capacity when it is not windy.

There are several solutions to tackling the challenge of ensuring sufficient generation capacity when it is not windy. Peak generation capacity may be provided from flexible generators, such as gas turbines. However, the latter also face downward price pressure (cf. challenge 1). New market solutions may be necessary to incentivize flexibility and/or capacity. Increasing cross-border transmission capacity to neighboring countries so as to enable power imports is an important flexibility option to cope with times of little or no wind. Flexible electricity consumption is another viable possibility. While certain types of flexible electricity consumption can only provide a solution for a limited number of hours, international grid connections can be used for cross-border electricity imports over longer periods of time without wind power production (for example over several weeks) [1].

Challenge 3: To balance wind power production patterns caused by variations in wind speed.

Although forecast methods have been improving over time, variations in wind speed may still lead to rapid fluctuations in electricity generation. This is especially the case if the production from wind power falls unpredictably, typically as a result of altered wind conditions. Electricity is a real-time good and requires instantaneous balancing of supply and demand. Increased integration with neighboring countries' energy systems can provide access to more generation and consumption sources capable of providing balancing [1]. There may be geographic smoothing effects leading to more stable renewable energy generation within a larger region. Also, cross-border balancing can be complimentary to the activation of flexibility options within one country with relatively short notice, e.g., via regional balancing markets.

Early grid integration – a prerequisite for early power market integration[6]

Early grid integration coincides with early electricity market integration in the Nordic countries. Nord Pool ASA was founded as early as 1996, when Norway and Sweden established a joint power exchange. Two years later, Finland entered the Nordic electricity market. In July 1999, the day-ahead market Elspot went operational. Elspot handles the auction of hourly power contracts for physical delivery the following day. East Denmark joined the Nordic power exchange in October 2000, leading to full integration of the Nordic power markets. West Denmark had already joined the Nordic power exchange the year before, in July 1999. At that time, the Western and Eastern Danish power systems were still two physically separated systems without transmission link [2]. However, there already existed interconnectors to their respective Nordic neighboring countries. For example, the four alternating current cables from East Denmark across the Øresund to Sweden had been erected in 1951, 1954, 1958 and 1963 [9]. The first existing interconnectors from Jutland (West Denmark) to Norway and Germany were established in the 1970s and 1960s, respectively [8]. The power systems of West Denmark (the area of Jutland and Funen) and East Denmark (the area of Zealand, including Copenhagen) were first connected to one another in August 2010 when the Great Belt Power Link went operational. The Great Belt Power Link is a 400 kV direct current connection with a capacity of 600 MW. While West Denmark (DK 1) is synchronized with the German system, and, thereby, with the continental synchronous area of Europe (former UCTE), East Denmark (DK 2) is synchronized with the Nordic system (former Nordel). In total, East Denmark has an export capacity of 2,300 MW to Sweden and Germany, and an import capacity of 1,900 MW (Table 1). The import capacity from Denmark to Sweden is lower than the export capacity of the same interconnector due to congestion in the Swedish grid

[4] The dominant support scheme in Denmark for onshore wind energy is a price premium paid on top of the wholesale market price of electricty.

[5] In Denmark the transmission system operator, Energinet.dk, initiated a market redesign process in spring 2014 where a Market Model 2.0 is developed in collaboration with a broad array of stakeholders (this is further described in [2]).

[6] Portions of this section are extracted from [2].

[8]. As for West Denmark, the total export capacity to Sweden, Norway and Germany amounts to 4,152 MW (excluding Bornholm). The import capacity is 3,812 MW (Table 1). With a total interconnector capacity to its neighboring countries of more than 6 Gigawatt, Denmark is characterized by a high level of connectivity. By comparison: Danish peak demand is also approximately 6 Gigawatt [1].

Table 1: Interconnectors from Denmark to neighboring countries, based on [8].

Interconnections from East Denmark (DK 2) to...	
...Sweden	• 4 AC connections (two at 400 kV and two at 132 kV) • Export capacity of up to 1,700 MW • Import capacity of up to 1,300 MW
...Germany	• Kontek interconnector (400 kV DC) • Capacity: 600 MW
Interconnections from West Denmark (DK 1) to...	
...Sweden (Konti-Skan)	• Konti-Skan (two 285 kV DC connections) • Export capacity from Jutland (DK): 740 MW • Import capacity: 680 MW
...Sweden (from Bornholm)	• AC connection (60 kV seacable) • Capacity: 60 MW
...Norway	• Skaggerak (4 DC connections with 2 at 250 kV, one at 350 kV and one at 500 kV) • Capacity: 1,632 MW
...Germany	• 4 AC connections from the Danish town Kassø (two at 400 kV and one at 220 kV) and Ensted Power Station (220 kV) + one 150 kV connection from Ensted Power Station to Flensburg • Import capacity: 1,500 MW • Export capacity: 1,780 MW (depending on congestions in surrounding grids)
Interconnector from Western Denmark to Eastern Denmark	
From Jutland-Funen to Zealand	• Great Belt Power Link (400 kV DC connection) • Capacity: 600 MW

Interconnectors from Denmark to neighboring countries: The major flexibility option for wind integration[7]

The market-based exchange with Denmark's neighboring countries is one of the most important means of integrating wind power production. The bulk of Danish wind power is installed in West Denmark with a total of more than 4 GW capacity (843 MW offshore wind and 3,194 MW onshore wind). Around 1 GW wind capacity is located in East Denmark (428 MW offshore wind and 608 MW onshore wind energy) [11]. As aforementioned, the total interconnector capacity from Denmark to Norway, Sweden and Germany is about as high as Danish peak demand. The complementary generation mixes in the Nordics – Denmark, with its increasing wind shares, and Norway and Sweden, with their hydropower-based systems – have worked advantageously in balancing electricity supply in the Nordic region. The integrated Nordic power market ensures that the cheapest generators along the merit order curve are prioritized for electricity production. For example, it allows Nordic hydropower stations to function as cheap and effective energy storage for wind power, the so-called "green battery." When electricity prices are low due to high levels of wind power generation, hydropower stations withhold their production. By the same token, when electricity prices are high, they increase their production.

[7] The second part of this section is extracted from [1].

Market coupling has been an important measure for the efficient utilization of interconnectors. Within Nord Pool, Denmark has been coupled implicitly with Norway and Sweden since 1999/2000, whereas an explicit day-ahead auction was used for the connections to Germany until 2009. Figure 1 shows the monthly average electricity prices from January 2002 to April 2015 in West Denmark and Germany compared to the (average) system price in the Nordic countries. The Nordic electricity prices are highly influenced by the amount of precipitation in Norway (whether it is a dry or a wet year), which relates directly to the available hydropower in Norway. A wet year results in lower electricity prices and vice versa. As illustrated by Figure 1, there are various factors influencing price fluctuations: precipitation levels, CO2 and fuel prices, as well as the development of power demand. While wind energy accounts for a high share of Danish electricity consumption, it only represents a limited share of total electricity supply within the Nordic power system. The storage capacity of Nordic hydro reservoirs is approximately 100 TWh, which is over three times more than annual Danish electricity demand.

Figure 1: Spot market prices in Denmark between 1999 and 2014, based on [12] and [1], p. 22.

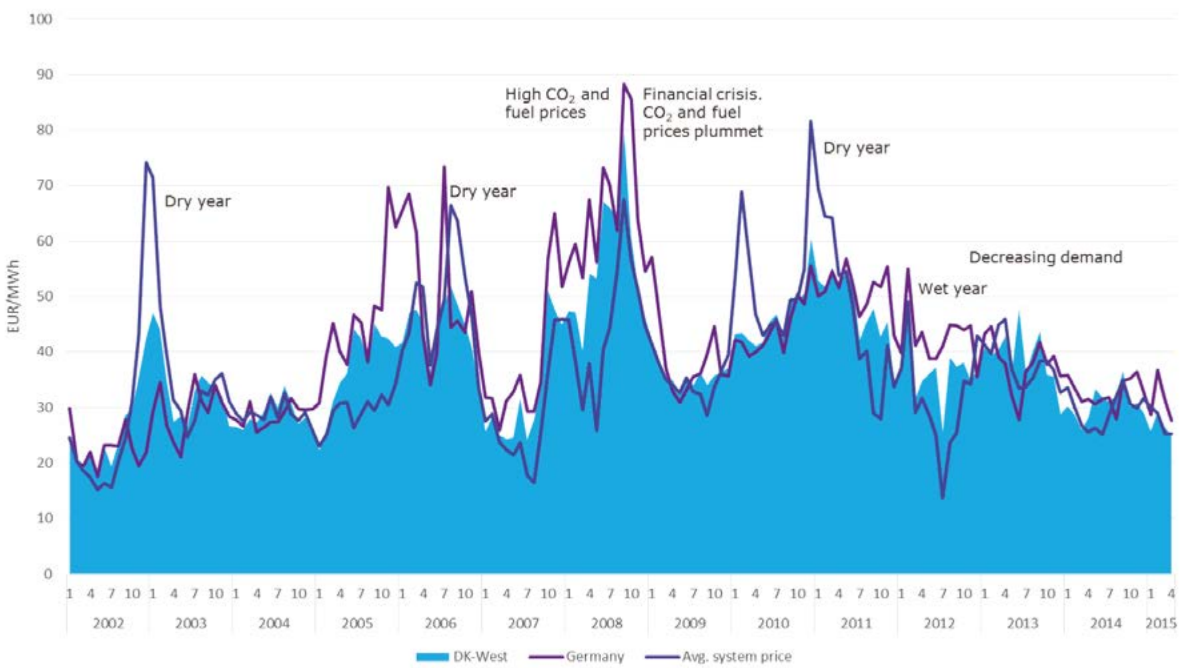


Figure 2 shows imports and exports from Denmark to neighboring countries in 2015, on a monthly basis. The year 2015 was characterized by relatively high net imports of electricity, which lead to a significant reduction of coal-fired electricity generation (accounting for 35.8 percent). Also, there was a high share of wind energy contributing to 41.8 percent of power production [6]. In terms of monthly net imports and exports, from February to October 2015 Denmark exported electricity to Germany while importing electricity from Norway and Sweden. This is different from, e.g., the year 2014, when Denmark still mostly imported from Norway and Sweden (with only limited exports to these countries), but when imports from and exports to Germany were more balanced on an annual basis (Figure 3).

The monthly figures for imports and exports only show on an aggregated basis how interconnectors were utilized each month of a year. The case for trade results from hourly price deviations between Denmark and its neighboring countries. Therefore, Figure 2 and Figure 3 have to be interpreted with caution. The actual hourly trade patterns are not represented by these figures as the latter only indicate net values for exports and imports. In order to analyze the correlation between high wind energy feed-in and exports from Denmark to its neighbors, it is necessary to use a higher resolution of the time scale. This is described in the following section.

Figure 2: Import and export of electricity from Denmark to neighboring countries in 2015. Imports to Denmark from abroad are indicated by positive numbers. Exports from Denmark to abroad are indicated by negative values [10].

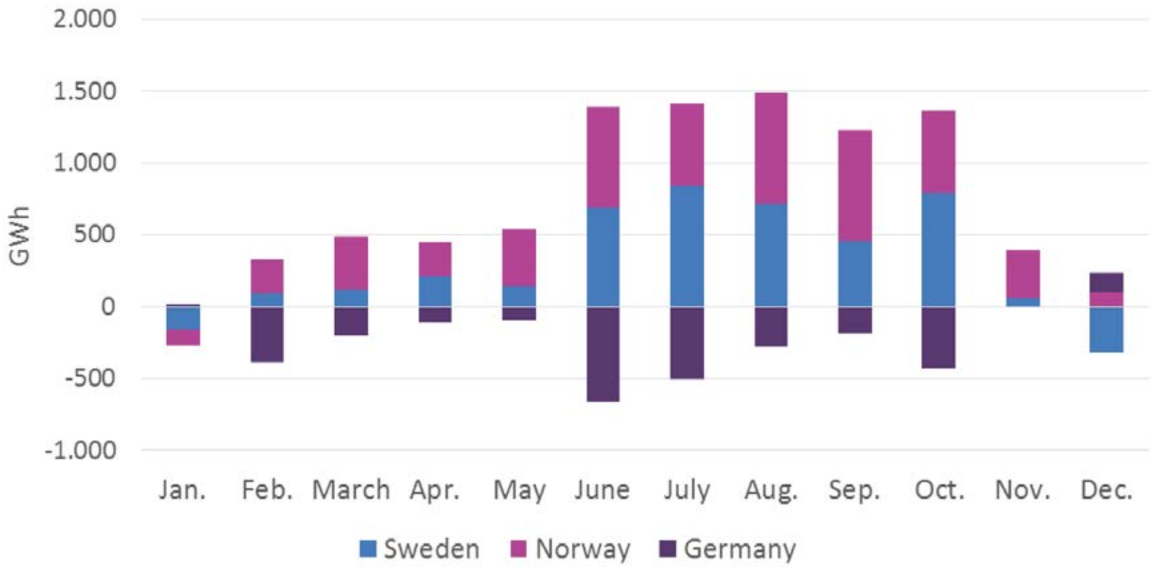
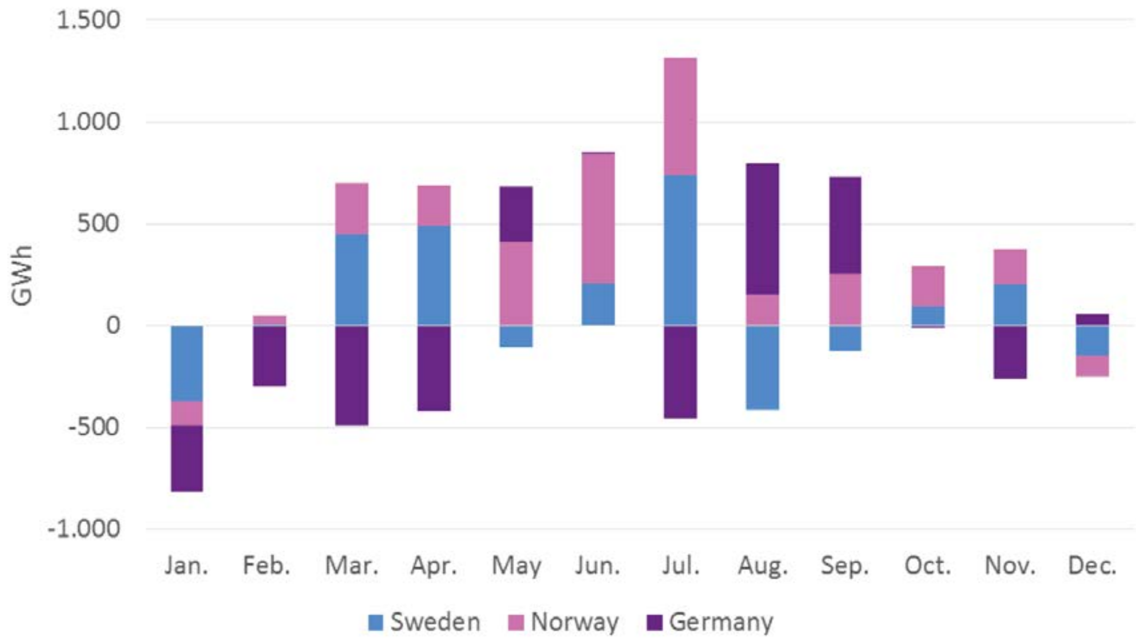


Figure 3: Import and export of electricity from Denmark to neighboring countries in 2014. Imports to Denmark from abroad are indicated by positive numbers. Exports from Denmark to abroad are indicated by negative values [13].



Wind power generation and exports[8]

In the following, we look into the correlation of wind power generation in West Denmark – typically coinciding with low wholesale electricity prices – and the magnitude and direction of power flow on interconnectors to Norway, Sweden and Germany. There is a clear correlation between the power flow on the interconnectors to Norway and Sweden and wind power generation in Denmark: during hours of high wind power production in Denmark, the interconnectors are predominantly used for export, and vice versa. This can be observed for 2002 and still for 2014 (Figure 4). In this respect, the Nordic power system functions as a flexibility option for integrating Danish wind power.

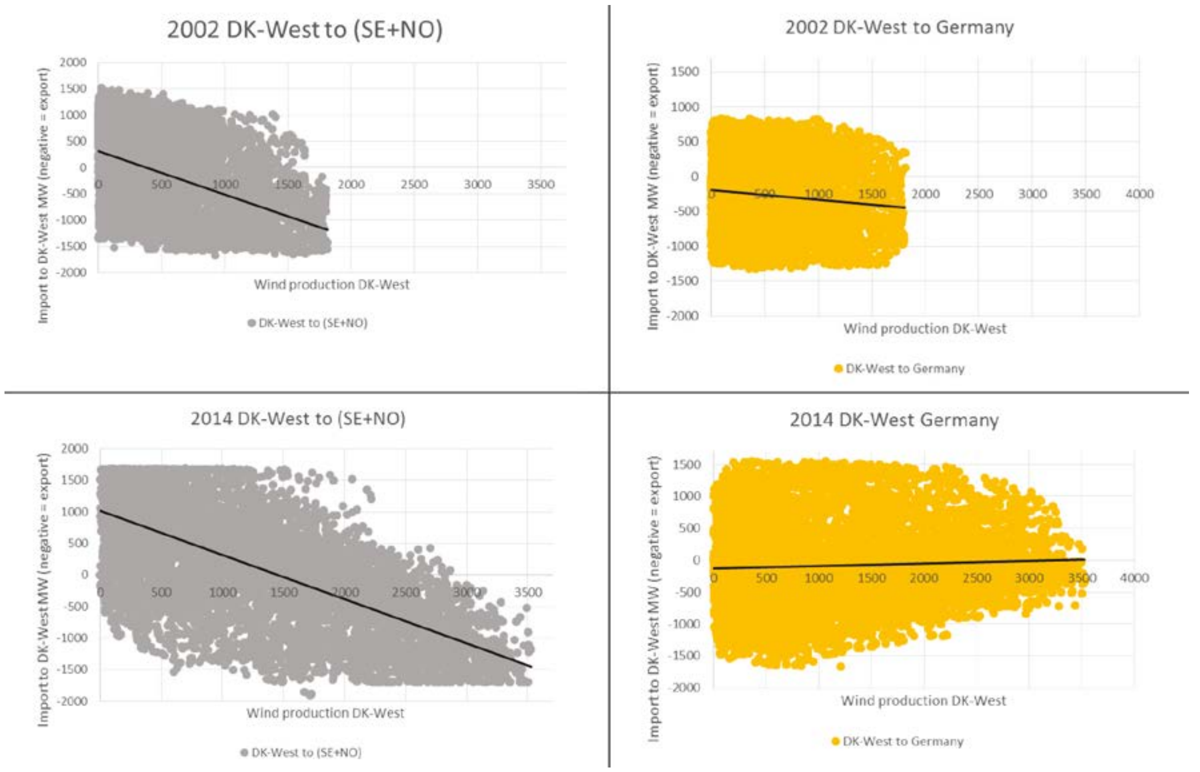
For the year 2002, we can see a similar correlation for the utilization of the transmission link between West Denmark (DK1) and Germany, though not as distinct. However, Figure 4 also shows that for 2014, there is no clear correlation. In high wind situations with wind power generation exceeding 1 Gigawatt, the full export capacity is not utilized anymore. This can be attributed to the fact that the southbound interconnector capacity between the control area DK 1 and Germany available to the spot market has decreased gradually over the past years. The reduction in interconnector capacity is due to congestion in the internal German electricity grid. High wind energy feed-in in the North of Germany, where the bulk of wind power capacity is installed, usually coincides with high power production in Denmark. While the available southbound interconnector capacity was on average 1,000 to 1,200 MW until 2008, only 300 MW were available in the first months of 2015. While interconnector capacity available for trade has been on the decline, the technical capacity has been increased from 1,200 MW in 2002 to 1,780 MW in 2015 [1]. This example shows how internal grid expansion can also become crucial for cross-border trade.

A Nordic-German Perspective on European Grid Integration

Overview

As the share of renewable energy sources in electricity production increases, closer integration of regional power systems within Europe becomes an appealing option for integrating fluctuating power generation,

Figure 4: Correlation between wind power generation in West Denmark and flows to Sweden/Norway and Germany [1], p. 24.



8 Based on [1], pp. 23f.

such as wind energy. There are numerous benefits associated with increased integration of the Nordic and German electricity systems, notably, due to the interplay of different generation mixes: cross-border balancing (hydropower as a “green battery”), smoothing effects in terms of wind energy feed-in patterns and wholesale electricity prices, enhancement of European market integration, trade benefits for the entire region, and price convergence. Germany has the objective of supplying at least 80 percent of its electricity consumption from renewable energy sources by 2050. Denmark is striving for complete independence from fossil fuels by 2050. At the same time, there are vast untapped potentials of wind energy in Norway, Sweden and Finland, and already existing hydropower reservoirs. While increased integration leads to an overall welfare gain for the entire region, the distribution of benefits may differ across countries. In order to shed some light on these issues Agora Energiewende and the Stockholm-based think tank Global Utmaning initiated a study on “Increased Integration of the Nordic and German Electricity Systems” [14][15]. For the purpose of this study, “increased integration” between the Nordic countries and Germany refers to an increase in transmission capacity between and within the countries (so-called “hinterland integration”). The aim of this study is to assess and discuss the economic and climate effects of further integrating the Nordic and German power systems. Firstly, the study comprises an analysis of the impact of increased integration with varying shares of renewable energy sources from the microeconomic perspective of the electricity market (Work Package 1). Secondly, the study analyzes the macroeconomic effects of increased integration on different countries and stakeholders in the Nordics and Germany (Work Package 2). This combined analysis allows to identify negative spillover effects that need to be mitigated in order to share benefits and to create acceptance of increased integration of power markets.

Research was carried out by an international consortium consisting of Ea Energy Analysis and DTU Management Engineering (Work Package 1), and DIW Berlin, Department Energy, Transportation, Environment (Work Package 2).The study was completed and presented at a public dissemination event in Berlin in June 2015.

In the following, there will be a brief overview of the methodology and of some key findings. The long version of the study, with detailed modeling results and a discussion of the macroeconomic effects, is available online [14]. For a quick overview, a comprehensive summary of findings can also be found on Agora Energiewende’s website [15].

Scenarios and methodology

The timeframe of the study is the year 2030. The study comprised four core scenarios, with two exogenous parameters of variation:

- The level of renewable energy deployment in the electricity sector (RES-E): moderate vs. high level of RES-E deployment. In the High RES-E scenarios, wind power production in the Nordic countries quadruples as compared to the base year 2013. As for Germany, the High RES-E scenarios is characterized by a heavy increase in wind power production, both onshore and offshore, and an increase in solar PV.

- The level of grid integration between Nordic countries and Germany: moderate vs. high level of grid integration. The High Transmission (High Trans) scenarios include transmission projects planned for commissioning until 2030, based on the Ten Year Network Development Plan (TYNDP) 2014. The Moderate Transmission (Mod Trans) scenarios comprise transmission projects to be completed until 2020, based on the TYNDP 2014.

The combination of the two parameters of variation leads to four core scenarios (Table 2).

A power market simulation was run in order to simulate hourly power production patterns based on least cost optimization (least cost dispatch). For these quantitative analyses the partial equilibrium model Balmorel was used. The model simulates the dispatch of generation units, power market prices (an hourly resolution is applied in this study), system costs, as well as infrastructure investments; the hourly simulations are based on investment decisions defined in a preceding investment model run. Based on these quantitative modeling results, the distributional effects of increased integration among stakeholders and across countries were analyzed.

Table 2: Scenario setup with two parameters of variation: RES-E shares and transmission capacity [15].

More RES-E →

More Trans-mission ↓

	Moderate RES-E	High RES-E
Moderate integration of grids	ModRE_ModTrans	HighRE_ModTrans
High integration of grids	ModRE_HighTrans	HighRE_HighTrans

Extract from "Increased Integration of the Nordic and German Electricity Systems", Summary of Findings [15], pp. 5-6.[9]

Key Findings and Conclusions

1. Increased integration between Nordic countries and Germany will become ever more important as the share of renewables increases. The more renewables enter the system, the higher the value of additional transmission capacity between Nordic countries and Germany will become. In particular, additional generation from renewables in the Nordics – reflected in the Nordic electricity balance - will increase the value of transmission capacity. There is a lot of potential for trade, due to hourly differences in wholesale electricity prices throughout the year.

The Nordic countries have large untapped potentials of wind energy and existing hydropower reservoirs. By 2035 Germany aims for a 55 to 60 per cent share of renewables in final electricity consumption as part of its "Energiewende" (energy transition), while by the same year Denmark plans to have an entirely renewable electricity and heat sector. Increased interconnection facilitates renewable based electricity generation in the region and opens up greater cross-border balancing possibilities for integrating fluctuating levels of renewable energy. There is substantial potential for electricity trade from the differences in hourly wholesale electricity prices between the Nordic region and Germany. Trade potential between the two regions emerges if high and low wholesale electricity prices occur at different hours. If wind power production in Norway, Sweden and Germany quadruples in the next 15 years, then wholesale electricity prices will be lower in the two Nordic countries than in Germany for approximately 7,000 hours per year. This implies that the main direction flow is from Norway and Sweden (low price areas) to Germany (high price area), with Nordic countries exporting electricity to Germany annually. The interconnectors are used to a lesser extent for export from Germany to the Nordic countries. The possibility of exporting additional generation from renewables increases the value of additional transmission capacity. This underscores the viability of the projects of the Ten Year Network Development (TYNDP) 2014 for the year 2030. If renewable deployment is only moderate, however, there will be fewer hours with electricity surplus in either region. This reduces the price spread between the Nordic and German regions and lowers the value of additional transmission capacity considerably.

2. A closer integration of the Nordic and the German power systems will reduce CO2 emissions due to better utilisation of renewable based electricity. This is caused by reduced curtailment of renewables, improved integration of additional renewable production sites, and increased competitiveness of biomass-fuelled power plants.

A high deployment of electricity from renewable energy sources in the Nordic countries and in Germany will lead to a significant reduction of CO2 emissions by 2030. Based on our assumptions in the High Renewable scenario, the electricity sector and the heat sector (the latter in Scandinavia) can expect a reduction of 40 to 55 per cent relative to 2013. Increased grid integration, between and within countries, will improve options for choosing sites with good (wind) resources. This may allow wind deployment further north in Norway and

[9] This section on Key Findings and Conclusions on behalf of Agora Energiewende are taken as a direct quotation from the Summary of Findings [15], pp. 5-6.

Sweden, where wind conditions are more favourable. Furthermore, increased grid integration will reduce curtailment of hydro and wind power, and hence raise the level of CO2 free renewable feed-in. Finally, biomass-fuelled power plants (such as those in Denmark) may become more competitive due to better market integration. For creating investor confidence in renewable generation, sufficient grid capacity is necessary to accommodate the feed-in of new production sites connected to the grid.

3. Higher integration will lead to the convergence of wholesale electricity prices between Nordic countries and Germany. But even with more integration, the Nordic countries will see lower wholesale electricity prices if they deploy large shares of renewables themselves. In general, additional integration will lead to slightly higher wholesale electricity prices in the Nordics and slightly lower prices in Germany. But this will be counteracted by the decreasing price effect that higher wind shares in the Nordics have on the wholesale power market.

Average wholesale electricity prices are lower in the Nordic region than in Germany. The level of wholesale electricity prices is affected both by the level of renewable energy deployment and by the level of transmission capacity. Grid integration triggers price convergence, translating into a relative increase of average wholesale electricity prices in the Nordic countries and into a slight decrease of average prices in Germany. If there is high renewable deployment (wind) in Scandinavia, a relative drop in wholesale electricity prices will be observable in the Nordic region, partially counteracting the price increase induced by more transmission capacity. In general, additional integration benefits power producers in countries with relative price rises and electricity consumers in countries with relative price drops. This implies that in the Nordic countries hydropower and wind generators will gain the most in stakeholder rent, while Nordic consumers will face higher wholesale electricity prices. By contrast, in Germany consumers will benefit from lower electricity prices, whereas power producers will mostly incur losses. Notably, the Nordic power market is smaller in size and less integrated with additional neighbouring systems. Hence, the effects of additional transmission capacity on prices and on the distribution of stakeholder rent will be more pronounced in the Nordic countries than in Germany.

4. Distributional effects from increased integration are significantly higher across stakeholder groups within countries than between countries. This strongly impacts the incentives of market players such as electricity producers or consumers (e.g., energy-intensive industries) for or against increased integration. Distributional effects need to be taken into account for creating public acceptance for new lines and for the cross-border allocation of network investments.

The costs and benefits of increased integration will be allocated asymmetrically across countries. This could hamper the regional development of the electricity system, especially if internal line upgrades are needed for higher cross-border integration. Denmark is likely to play a special role as a transit country, serving as a hub between Nordic countries and Germany. The distributional changes among stakeholders – different types of producers and consumers – will be substantially higher in one single country than the distributional changes from integration between countries. This will strongly impact the incentives of different market players such as electricity producers and consumers for or against increased integration. Competitiveness of energy-intensive industries is a sensitive issue of national industrial policy. For large and energy-intensive industrial power consumers, the cost of electricity supply is mostly driven by the electricity price at the wholesale market. Therefore, varying or increasing electricity prices will have a non-negligible impact on the cost structure of these branches in relative terms. Electricity producers and consumers will be affected asymmetrically across countries. The implied repercussions of stronger integration provide a base for understanding and shaping targeted policy measures at the European and national levels. European cross-border cost allocation schemes need to take this into account if they are to avoid opposition by countries or stakeholders, which could undermine interconnector projects. Increased system integration is a prerequisite for connecting high volumes of renewable energy in the long run.

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