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

STUDY (SUMMARY OF FINDINGS)

Agora Energiewende

GLOBAL UTMANING

Ea Energy Analyses

DTU

DIW BERLIN

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IMPRINT

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Preface

Dear Reader,

Increased integration of power systems is one of the prerequisites for the completion of the EU internal energy market – and with it the achievement of higher cross-border transmission capacities between European countries. The Nordic countries have vast potentials in renewable energy, such as wind energy, together with already existing hydropower reservoirs.

As part of the *Energiewende*, the German electricity system is undergoing the transition toward a high share of renewable energy – wind and solar photovoltaics in particular. Increased integration of the Nordic and German electricity markets will bring mutual benefits for power systems, greenhouse gas emissions mitigation and the wider economy. At the same time, increased integration affects stakeholders such as power producers and consumers in different ways in different countries. These effects are important to consider when increasing public acceptance for new (cross-border) transmission lines.

Agora Energiewende and the Swedish think tank Global Utmaning have put these issues to a consortium of three leading European research institutes. The aim of the resulting study was to examine the impact of increased integration between Nordic countries and Germany with a variety of renewable electricity shares. The study is meant to foster dialogue and discussions across countries and stakeholders, and encourage further research. The findings, as well as the accompanying technical reports, have been published on Agora Energiewende's website.

I hope you enjoy the read.

Kind regards,
Patrick Graichen
Director Agora Energiewende

The Results at a Glance

1. **Increased integration between the 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.

2. **A closer integration of the Nordic and the German power systems will reduce CO_2 emissions due to better utilisation of renewable electricity.** This is caused by reduced curtailment of renewables, improved integration of additional renewable production sites and increased competitiveness of biomass-fuelled power plants.

3. **Higher integration will lead to the convergence of wholesale electricity prices between the 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 to 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.

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.

Content

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 percent 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 CO_2 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 CO_2 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 percent 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 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 CO_2 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.

Executive Summary

The Nordic countries have vast potentials in renewable energy, such as wind energy, together with already existing hydropower reservoirs. At the same time, as part of the "Energiewende", the German power system is undergoing the transition toward a system with high shares of renewable energy – wind and solar photovoltaics, in particular.

The aim of this study is to assess and discuss the economic and climate effects of further integration of the Nordic and German power systems through 2030. The project's analysis is both quantitative and qualitative.

We identified **four core scenarios** for future development with two parameters of variation:

→ the level of renewable energy deployment in electricity (RES-E), and
→ the level of grid integration between Nordic countries and Germany.

A partial equilibrium model – Balmorel – was used to simulate hourly production patterns (least cost optimisation). The model runs generated results for infrastructure investments, prices, generation and system costs at national and system levels. From these results we analysed the distributional effects of integration among stakeholders.

The study finds that renewable deployment is the major influencing factor for the generation mix. When more renewables enter the system, they induce an increased value of transmission capacity between the Nordic countries and Germany. High deployment of renewables in the Nordic countries, which is reflected in the Nordic electricity balance, increases the value of transmission capacity in particular.

In the case of moderate renewable deployment (ModRE scenario), our modelling results yield that almost 70 percent of the total national electricity production in the core countries of the model will be based on renewable energy sources in 2030. In the High Renewable scenario, an additional 128 Terawatt hours (TWh) of solar and wind feed-in is part of the generation mix. Germany's conventional generation is then reduced by 47 TWh as compared to the moderate renewable case. In total, the High Renewable scenario sees a generation increase in the Nordic-German region by roughly 50 TWh. The generation mix is only slightly affected by adding transmission capacity. Hence, an increase in transmission capacity has only a limited effect on the generation mix as such.

There is great potential for increased electricity trade between the Nordic countries and Germany. More renewables augment the value of transmission capacity. Power

Scenario setup — Table 1

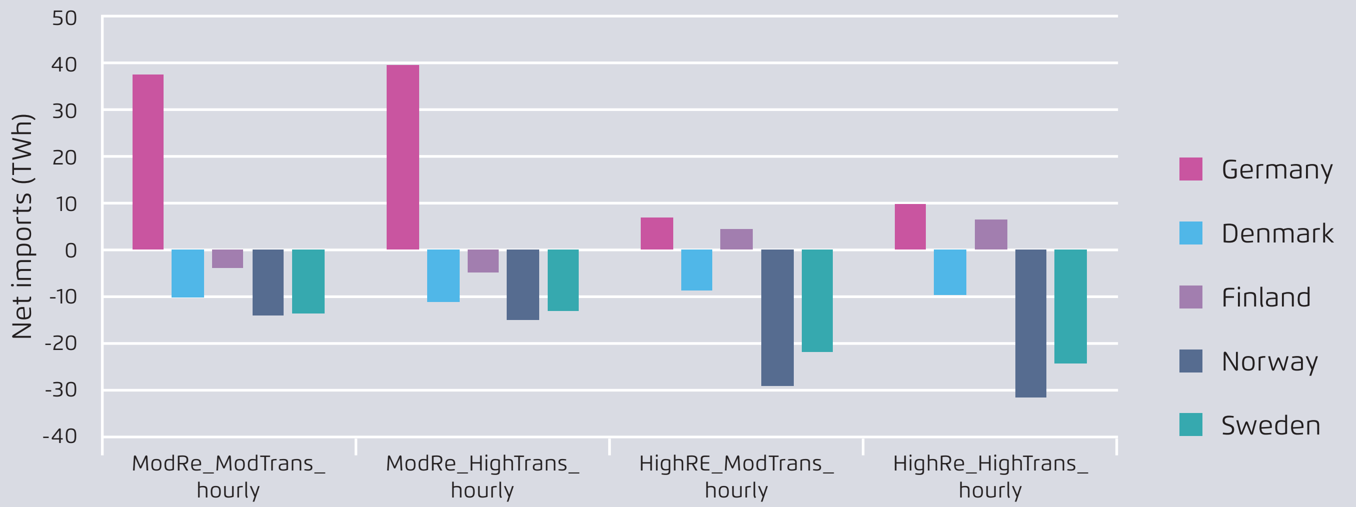
More RES-E →

More Transmission ↓

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

Ea and DTU, 2015

Net annual imports to the Nordic countries and Germany in the four scenarios. Imports include imports from surrounding countries. Negative net imports signify exports. Figure 1



Ea and DTU, 2015

will be exported yearly from the Nordics to Germany, but in reality trade patterns will be more complex, playing an important role in balancing variable (renewable) electricity production. The electricity balance, in particular the high renewable deployment levels in the Nordic countries in the High Renewable scenario, will be a crucial driver of increasing the value of transmission capacity.

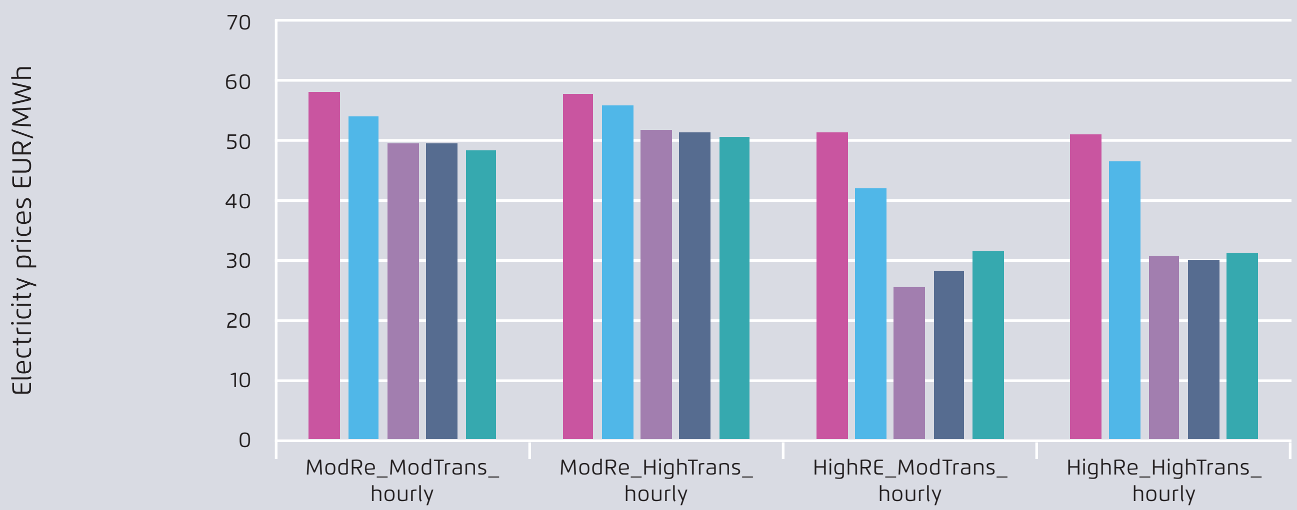
Generally, Scandinavia has relatively low wholesale electricity prices. Higher transmission capacity leads to increased market integration, and, hence, to higher average wholesale electricity prices in the Nordic countries and lower prices in Germany. Notably, in the High Renewable scenarios, the wholesale electricity prices drop sharply in the Nordic region relative to the moderate renewable deployment case. This price drop counteracts the price increase induced by more transmission capacity. In other words, even with more integration, the Nordic countries will face no significant wholesale electricity price increase as long as they deploy large shares of renewables themselves.

The wholesale price is affected both by the level of renewable energy deployment and by the level of transmission capacity. As shown in Figure 2, the major influencing factor for wholesale electricity prices is the level of renewable energy deployment.

According to the study's findings, the deployment of additional renewables in the Nordic countries and in Germany leads to a significant reduction in CO_2 emissions. While the emissions effect of additional transmission capacity itself is limited, an increase in transmission capacity constitutes a prerequisite for higher renewable integration. This shows again that increased renewable deployment is the main factor for achieving high emissions reductions. Increased interconnectivity of the grids can be regarded as a requirement for higher investment volumes in renewables.

From the power market and systems standpoint, increased grid integration has a positive welfare effect overall. Compared with welfare effects between countries, levels of redistribution are significantly higher across stakeholder groups within a single country. In general, increased integration benefits producers in countries with increasing wholesale electricity prices and consumers in countries with decreasing prices. In the Nordic countries, hydropower and wind generators stand to gain the most, while

Average annual wholesale electricity prices in 2030. Wholesale price level for the countries is expressed as a simple average across regions. In reality the wholesale electricity price will vary considerably in each country over the year. (Note that the wholesale price is not the consumer price, which includes additional costs such as taxes, levies and distribution fees.) Figure 2



	ModRe_ModTrans_ hourly	ModRe_HighTrans_ hourly	HighRE_ModTrans_ hourly	HighRe_HighTrans_ hourly
Germany	58	57	51	51
Denmark	54	56	42	46
Norway	49	51	25	30
Sweden	49	51	28	30
Finland	48	50	31	31

Ea and DTU, 2015

consumers face higher electricity prices. In Germany, electricity consumers benefit from lower prices, whereas power producers mostly incur losses. At the country level, the biggest beneficiaries are Norway and Germany in the case of moderate renewable deployment, and Sweden and Norway in the case of high renewable deployment. Notably, because the Nordic power market is smaller in size and is less integrated in other neighbouring systems, added transmission capacity has stronger effects on Nordic wholesale electricity prices.

Seasonal hydro storage in Norway and Sweden is often considered one of the main drivers for integration due to its flexibility, allowing it to compensate for wind generation fluctuations in the North Sea and Baltic Sea regions. Stronger integration provides opportunities for trade in both directions. Wholesale electricity market prices do not indicate clear additional benefits from integration for hydro storage. But other benefits may arise, such as improved integration of variable wind energy production or improved regional supply security through balancing annual inflow variations in Nordic hydropower during dry and wet years.

The distribution of benefits from increased integration strongly affects the incentives of different market players such as electricity producers or consumers for or against new (cross-border) transmission lines. These distributional effects need to be taken into account for creating public acceptance for new lines and for the cross-border allocation of network investments. A lack of incentives due to asymmetrical distribution effects could be levelled out by cross-border cost allocation schemes between countries. The price impact on individual stakeholders, such as specific consumer groups, depends on final electricity prices. In addition to energy and supply costs, these may include network costs, taxes and other levies. Energy-intensive industries in the Nordic countries are most directly exposed to an increase in wholesale electricity prices.

The aging electricity systems in the Nordics and in Germany are up for renewal. To increase their flexibility, new, forward-looking system designs are needed. Grid expansion and cross-border interconnectors constitute an important flexibility option for balancing variable generation across larger regions. Distributional effects introduce a political dimension in addition to economic considerations. The political dimension has a "good neighbours" element: prudent cost allocation schemes can facilitate the overall benefits of integration. Overarching goals, such as the completion of the European energy market and the *common* provision of security of supply, need to be taken into account when discussing the total value of increased integration. In the long run, costs are not the only thing that is important; total value creation is as well. We need continued regional dialogue across stakeholders and countries about cost sharing, incentives and future goals.

Summary of Findings

This **Summary of Findings** describes the approach and the major insights generated by the study "Economic and climate effects of increased integration of the Nordic and German electricity systems". It is structured as follows: first we describe the underlying motivation for this study, the methodological approach and its working assumptions; second we present key findings from two Work Packages; third we draw some conclusions and point out future challenges for policy making.

For more detailed information, see the full-length version of this study on Agora's website (www.agora-energiewende.de) and Global Utmaning's website (en.globalutmaning.se). The full-length version is composed of five parts:

- → Preface and Key Findings.
- → Executive Summary.
- → Chapter 1: Outlook for Generation and Trade in the Nordic and German Power System - Work Package 1 (Ea and DTU, 2015).
- → Chapter 2: Distributional Effects of System Integration and Qualitative Discussion of Implications for Stakeholders - Work Package 2 (DIW, 2015).
- → Appendix: Data Report to Work Package 1.

While this Summary of Findings gives a general overview over the project, the full-length version provides detailed findings for each of the Work Packages.

A. Why this study?

The aim of this joint study by Agora Energiewende and Global Utmaning is to assess and discuss the economic and climate effects of further integrating the Nordic and German electricity systems. For the purposes of this study, "increased integration" refers to investments in transmission lines. This comprises both interconnectors between the Nordic region and Germany, as well as increased transmission capacity within individual countries (so-called "hinterland integration"[1]). The Nordic countries have vast potentials in renewable energy, such as wind energy, together with already existing hydropower reservoirs. At the same time, as part of the "Energiewende", the German electricity system is undergoing the transition toward increasing shares of variable renewable energy – wind and solar photovoltaics (PV) in particular. With further deployment of renewable energy in Central and Northern Europe, an increased integration of the systems can result in better utilisation of renewable energy sources.

Earlier studies have pointed out numerous benefits of increased regional integration between the Nordic countries and Germany:

- → Increased integration leads to positive welfare effects for the entire region (see, e.g., Svenska Kraftnät, 2013a (Appendix Report)).
- → Electricity prices generally converge as integration increases (see, e.g., Svenska Kraftnät, 2013 and Twenties, 2013). Physical interconnection by means of transmission lines is a prerequisite for enhancing European market integration.
- → Price levels are stabilised, and there is less price volatility (smoothing effect) (see, e.g., Prognos, 2012, THEMA, 2013 and Twenties, 2013).
- → Increased integration allows for improved utilisation of energy sources and reduces overall costs of balancing the system (e.g., THEMA, 2013).
- → Flexible resources can be shared to a larger extent across regions and enable cross-border system balancing for integrating fluctuating renewable energy over a larger area. Indirect storage, in particular Nordic hydropower, can absorb excess electricity production by renewables and provide reserve capacity (e.g., Prognos, 2012).

1 By "hinterland integration" we mean domestic grid expansion and reinforcement measures within one country, as opposed to cross-border integration of interconnectors between two or more countries.

This project provides a combined quantitative and qualitative analysis of Nordic and German electricity system integration. The aim of the study is two-fold. First it examines the impact of increased integration with varying shares of renewable energy in the power system, i.e., high vs. moderate renewable deployment. This is done by means of a market simulation model of the electricity sector (Work Package 1). Second this study looks into the macroeconomic effects of increased integration on different countries and stakeholders on "both sides of the border" (Work Package 2). In this way, it contributes to our understanding of the sectoral perspective (i.e., the power system) and the overall distributive impact on producers, distributers and consumers along the value chain. Ways of sharing benefits from integration for compensating losing parties should be considered although overall welfare gains for society should constitute the key decision parameter. Identifying the stakeholders most affected by the changes in wholesale electricity prices induced by increased integration will help mitigate potential negative spillover effects.

B. How was the study carried out?

This study was initiated as a common project of Agora Energiewende, a Berlin-based think tank, and Global Utmaning, a Swedish think tank located in Stockholm. It was officially launched in August 2014 (project kick-off with research partners).

Its scope comprises two work packages, one quantitative and the other qualitative:

- Work Package 1: "Outlook for Generation and Trade in the Nordic and German Power System" (Chapter 1 of the full-length version of this study).
- Work Package 2: "Distributional Effects of System Integration and Qualitative Discussion of Implications for Stakeholders" (Chapter 2 of the full-length version of this study).

Work Package 1, the quantitative simulation part, was carried out by Ea Energy Analysis in collaboration with the Technical University of Denmark (DTU Management Engineering). Work Package 2, the qualitative part, was elaborated by the German Institute for Economic Research (DIW Berlin). The qualitative discussion is based on the quantitative results derived from the market simulation undertaken in Work Package 1.

As part of the project, a Stakeholder Advisory Group was established consisting of transmission system operators, representatives of associations, policy makers and other actors along the value chain. The stakeholders participating in the project were from the Nordic countries (Denmark, Finland, Norway and Sweden) as well as from Germany. Two Advisory Group Meetings were held during 2014. The first one, which took place on 26th September 2014 in Stockholm, focused on the underlying assumptions for the scenarios and on the methodology for the work packages. At the second meeting, held on 26th November 2014 in Berlin, preliminary results of the quantitative part were presented, followed by a discussion of the qualitative approach. In April 2015, stakeholders of the Advisory Group were invited to provide written comments on the draft final report.

The results and conclusions of this project do not necessarily represent the opinion of the members of the Stakeholder Advisory Group. Responsibility lies exclusively with Agora Energiewende, Global Utmaning, and the participating research institutions.

C. Approach and Key Assumptions

The study analyses the effects of closer integration of the Nordic and German electricity systems by increased investments in transmission lines. The study's **timeframe** extends to **2030**. The **geographical scope** of this study is the Nordic countries (Denmark, Finland, Norway and Sweden) and Germany. While the scenario variations focus on these countries, the model simulations of the quantitative part also include the Baltic Sea region, neighbouring countries to Germany and the United Kingdom.

Four Core Scenarios:
Grid Integration and Renewable Deployment as Drivers

In order to describe possible paths of future developments, **four core scenarios** have been established, with two parameters for variance:

- the level of renewable energy deployment in electricity (RES-E), and
- the level of grid integration between the Nordic countries and Germany.

The motivation for this scenario setup comes from the fact that an increase in renewables and higher grid integration will be two of the major driving factors for change in future Nordic-German electricity systems.

Assumptions for Grid Integration (Transmission Capacity)

The **assumptions for grid integration** are based on the Ten Year Network Development Plan (TYNDP 2014) developed by ENTSO-E, the European Network of Transmission System Operators for Electricity. The capacities include both existing interconnections, projects from the TYNDP 2012 and new project candidates from the TYNDP 2014. The **moderate grid integration scenario** (ModTrans) includes grid expansion projects envisaged by the TYNDP 2014 to be implemented by 2020. These projects comprise grid expansion within and between the Nordic countries as well as Germany (Figure 1). Projects within and between neighbouring countries are included if they are planned to be finished by 2025. Transmission capacity expansion is expected between Norway and Germany, Denmark and Germany, and among the countries in the Baltic region and the United Kingdom. In the ModTrans scenario, the total transmission expansion within the entire region relative to transmission capacities as of 2013 amounts to approximately 47 Gigawatt (GW). Note that some adjustments in the grid assumptions have been made, as compared to the TYNDP 2014:

- Internal reinforcements in Norway have been estimated based on feedback by the Norwegian transmission system operator (the reinforcements between NO_M and NO_MW, as well as between NO_MW and NO_SW).
- The TYNDP mentions a transmission connection between Sweden (SE_M) and Western Denmark (DK_W). Based on feedback by participating transmission system operators, this transmission line has not been included.
- A new transmission line between Sweden and Latvia is included in the calculations. The project is mentioned in the TYNDP 2014 as a possible alternative to the Hansa PowerBridge project connecting Sweden and Germany, which is included in the High Transmission scenario. In retrospect, the transmission line between Southern Sweden and Latvia might not have been included, but the effect of including it nonetheless is assessed to be limited. The inclusion in the modelling does not imply a prioritisation of this line over the Hansa PowerBridge between Sweden and Germany.

Scenario setup — Table 1

More RES-E →

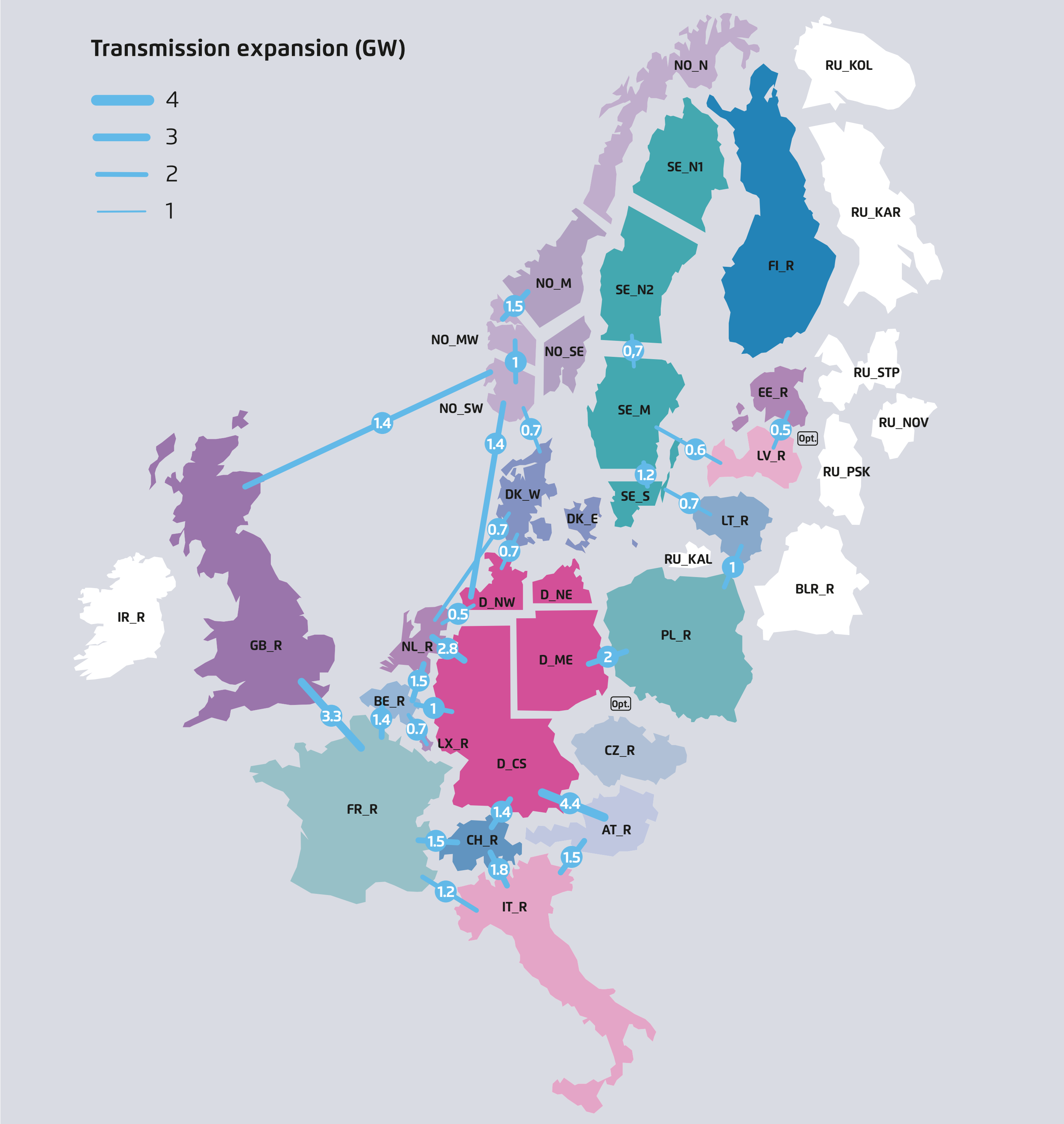
More Transmission ↓

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

Ea and DTU, 2015

Additional transmission capacity (relative to 2013) for the scenarios with moderate integration of grids (ModTrans scenarios), based on grid expansion projects envisaged by the TYNDP 2014 for 2020 in the German-Nordic region. Germany is modelled as one price zone without any internal bottlenecks.

Figure 1



Ea and DTU, 2015

Additional transmission projects in the High Transmission (HighTrans) scenarios. Data on transmission capacity, commissioning years and cost estimates are based on TYNDP 2014. Table 2

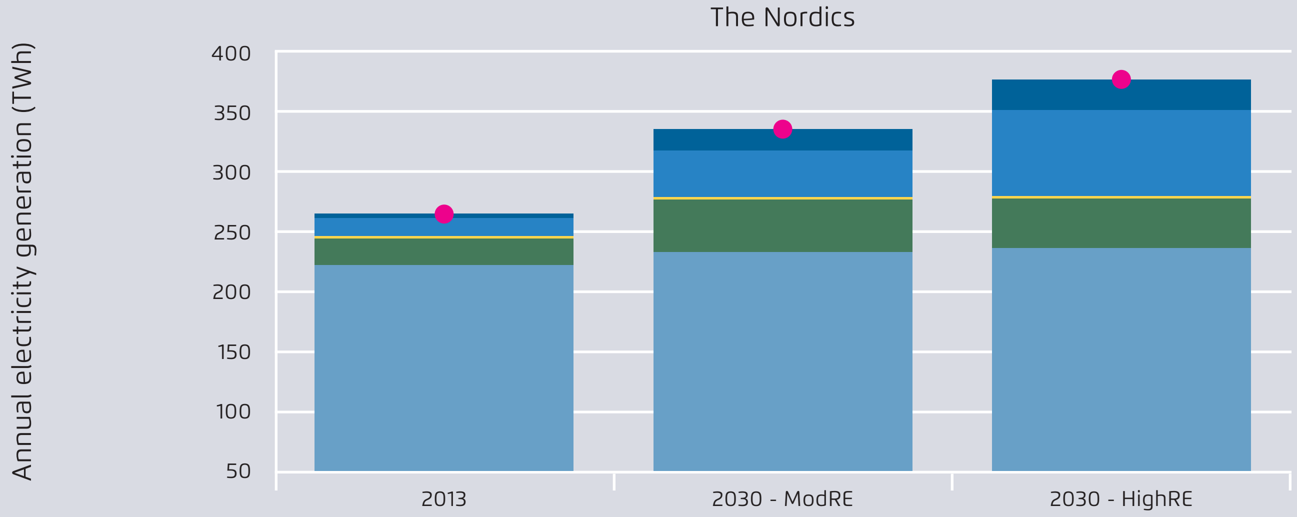
Core Countries					
Project	**From**	**To**	**Capacity (MW)**	**Year**	**Estimated Cost (M€)**
Westcoast	DK_W	DE_NW	500	2022	170-210
Hansa PowerBridge	SE_S	DE_NE	700	2025	200-400
3rd AC Finland-Sweden	SE_N1	FI_R	1000	2025	64-120
Finland-Norway	NO_N	FI_R	500	2030	300-700
Norway-North Sweden	NO_N	SE_N2	750	2030	140-330
East Denmark-Germany	DK_E	DE_NE	600	2030	500-610
Sum of costs					**1,374 - 2,370**
Internal Reinforcements					
NordBalt Cable Phase 2	SE_S	SE_M	700	2023	170-270
Res in mid-Norway	NO_M	NO_N	1200	2023	870-1,500
Great Belt II	DK_W	DK_E	600	2030	390-480
Sweden north-south	SE_M	SE_N2	700	2030	800-1,400
Sum of costs					**2,230 – 3,650**
Total cost of High transmission scenario					**3,604 -6,020**
Annualised cost (4% interest rate, 30 year lifetime)					**208 - 348**
Annualised cost (5% interest rate, 20 year lifetime)					**289 - 483**

Ea and DTU, 2015

→ The TYNDP mentions a possible transmission line between Denmark and the United Kingdom (VikingLink) for 2030. Since this is a connection between a core country of the study and a third country, the line has not been included in the calculations, which is in line with the scenario approach of this study. However, recent announcements by the Danish system operator Energinet.dk and the British Energy Regulator OFGEM suggest that the realisation of this project is more likely to be closer to already 2020. Another link between the Nordic countries and the United Kingdom (the link between Norway and the United Kingdom) is planned to be commissioned in 2020 and therefore included in the calculations.

→ The TYNDP mentions a possible advanced direct current (DC) connection between Denmark and Germany as part of the development of the offshore wind farms

RES-E deployment scenarios and current generation level for the Nordics. Figure 2



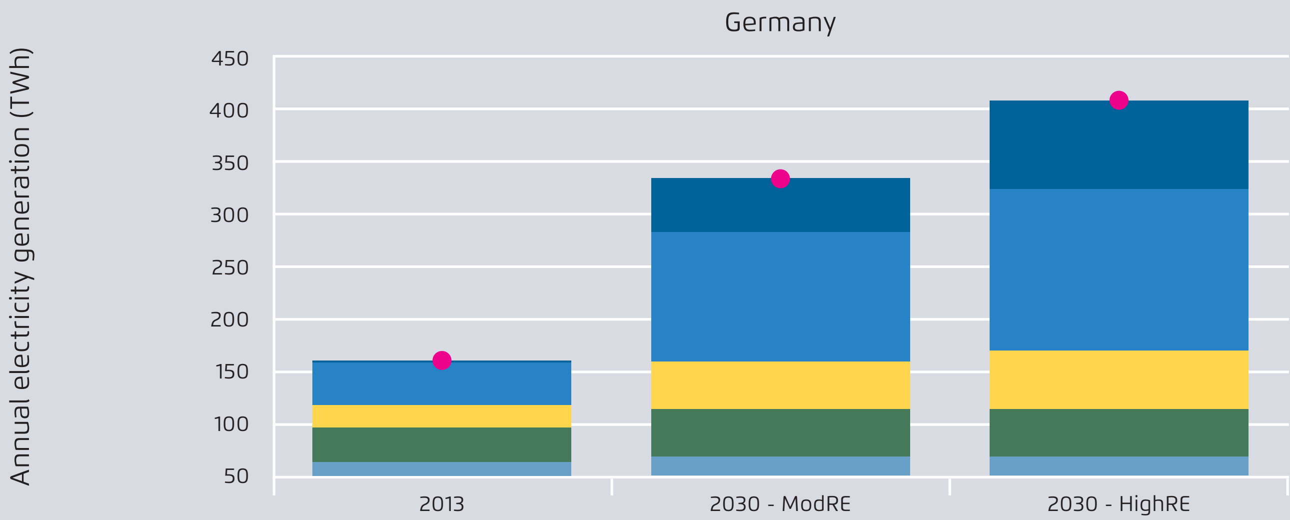
	2013	2030 - ModRE	2030 - HighRE
Offshore wind	5	20	29
Onshore wind	21	47	85
Solar	0	1	1
Biomass	28	52	47
Hydro	209	216	216
Total RE	263	336	378

Ea and DTU, 2015

Kriegers Flak (Denmark) and Baltic 1 and 2 (Germany). By the time this study began, this advanced grid solution had been suspended. Both Denmark and Germany are currently planning conventional alternating current (AC) connections to their respective wind farms. A connection between Denmark and Germany via wind farms is therefore not included in the calculations. However, a connection between the two countries via the offshore wind farms is still an option, e.g., by establishing a back-to-back converter to connect the two systems (note that Eastern Denmark and Germany are not within the same synchronous area.)

The **high grid integration scenario** (HighTrans) additionally incorporates grid projects of the TYNDP 2014 within and between the Nordic countries and Germany that are to be commissioned by 2030. Table 2 shows the ten transmission projects included in the HighTrans scenarios in addition to the ModTrans grid projects. These additional grid projects within and between the Nordic countries and Germany increase transmission capacity by an additional 7.3 GW. In particular, there is an increase in cross-border capacity between Sweden and Germany (Hansa PowerBridge), as well as between Denmark and Germany. In addition, there is increased interconnection between the Nordic countries, i.e., Norway, Sweden and Finland. Note that in terms of cost allocation, it can in some cases be difficult to explicitly determine which share of the investment cost of internal lines is clearly induced by increased cross-border trade, or whether it can also benefit the integration of national power production, such as increasing shares of renewables. The cost data are based on the TYNDP 2014. No additional cost assessments have been carried out for this project.

RES-E deployment scenarios and current capacities for Germany. Figure 3



	2013	2030 - ModRE	2030 - HighRE
Offshore wind	2	59	95
Onshore wind	59	141	178
Solar	32	52	63
Biomass	46	53	53
Hydro	19	20	20
Total RE	158	325	409

Ea and DTU, 2015

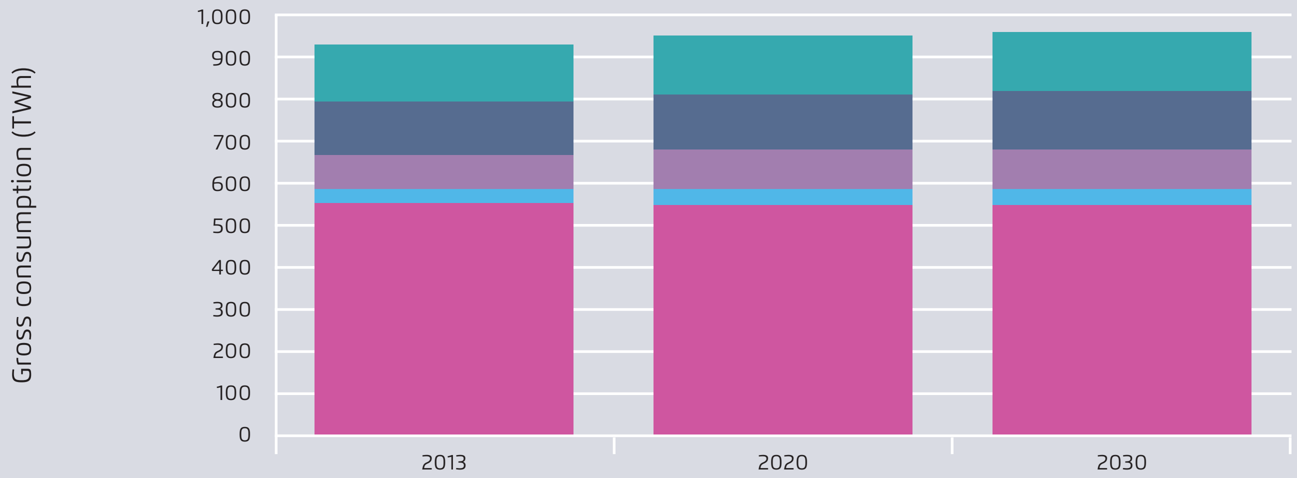
Assumptions for Renewable Energy Deployment

As for **renewable energy assumptions**, there is a scenario with high RES-E shares (HighRE scenario) and one with more moderate RES-E deployment (ModRE scenario). Official national data (e.g., based on scenarios by regulatory agencies or government objectives) have been applied where available. The reasoning behind this choice of approach is that national policies, European renewable energy targets and support schemes primarily drive renewable energy. For the HighRE scenarios, for some countries Vision 4 ("Green Revolution") of the TYNDP 2014 has been used as the basis for assumptions on high renewables deployment. Figure 2 and Figure 3 present the RES-E deployment assumptions versus the current level of RES-E for the Nordic countries and Germany. For Norway and Sweden, hydropower is assumed to be the same in both scenarios for 2030. But the HighRE scenario contains an increase in wind power production that is up to more than four times as high as today (Figure 2). A large increase in onshore and offshore wind energy has also been assumed for Germany. In the HighRE scenario, this equals almost 4.5 times the amount of wind power generation in 2013 (Figure 3). More detailed information on assumptions can be found in the Data Report attached to Work Package 1 in the full-length version of this study.

Additional Assumptions

Fuel and CO_2 prices are based on the IEA World Energy Outlook (2013) and assumed constant in all scenarios. Their influence on RES-E deployment is not a subject of the analysis. Other generation capacities are based on a bottom-up approach from current national plans (including dates for official decommissioning, such as Germany's nuclear phase-out schedule). Likewise, assumptions for demand are based on national forecasts (Figure 4).

Projected electricity demand for individual countries (including grid losses and excluding own consumption of power plants, electricity consumption for district heat production in, e.g., large heat pumps, and electricity consumption for pumped hydro storage) Figure 4



	2013	2020	2030
Sweden	137	140	139
Norway	128	132	139
Finland	84	94	94
Denmark	35	37	40
Germany	555	553	552

Ea and DTU, 2015; Data Report

Approach of Work Package 1:
Quantitative Simulation of the Power Market

For the modelling of the future energy system, we used a partial equilibrium model – **Balmorel**. The model is based on a detailed technical representation of the existing power system. It incorporates power and heat generation facilities as well as the most important bottlenecks in the overall transmission grid. The study's main results are a **least-cost optimisation** of production patterns for all power units. All final results are based on hourly simulations (least-cost dispatch of the power system). These hourly simulations are based on investment and decommissioning decisions defined in a preceding model run with aggregated time resolution. The **core countries** in this study consist of Germany and the Nordic countries (Norway, Denmark, Sweden and Finland). In addition, the model contains data on the remaining countries in the Baltic Sea region (Estonia, Latvia, Lithuania and Poland) and other surrounding countries (Netherlands, Belgium, France, Italy, Switzerland, Austria, Czech Republic, Great Britain and Ireland) to account for interdependencies. Some countries are divided into regions, reflecting potential transmission bottlenecks within the electricity system. In this study, Germany is considered as one power region, and hence represented by a single price zone.

Approach of Work Package 2:
Distributional Effects and
Qualitative Discussion of Stakeholder Implications

Based on the modelling results of Work Package 1, Work Package 2 analyses the distributional effects and discusses implications for stakeholders[2] and network development.

2 Note that the term "stakeholder" used throughout Work Package 2 refers to stakeholders in general, and not to the members of the Advisory Group of this project. Stakeholders in general may com-

As mentioned above, Work Package 1 yields market simulation results. The latter include generation capacity investments, prices, generation and system costs at national and system levels for the electricity sector. Building on these results, Work Package 2 provides an analysis of the distributional effects of integration at the stakeholder level. From the prices and quantities obtained in the power market simulation with Balmorel (energy only market) we calculate stakeholder rent for electricity consumers and electricity producers of the different technologies (**distributional effects among stakeholders**) as well as congestion rent. Next, at the **level of system cost**, we determine changes in capital costs and in operation and maintenance (O&M) costs for power generation from increased integration. The combined distributional effects among stakeholders for each country together with the changes in system cost yield the integration benefits for each country. A qualitative discussion of the impact on different types of consumers sheds light on the exposure or "vulnerability" of specific consumer groups caused by power price changes (such as energy intensive industries). Finally, a qualitative discussion introduces background information on incentive models to facilitate network investment with cross-border spillover relevant for Nordic-German integration – i.e., merchant transmission lines, inter-TSO compensation and Projects of Common Interest. Thereafter, the discussion touches briefly on aspects that may be relevant for increasing market integration (e.g., different price zones).

D. Findings and Highlights

Renewable deployment will be a major influencing factor for the generation mix. When more renewables enter the system, they induce an increased value of transmission capacity between the Nordic countries and Germany. In particular, a high surplus in the Nordic electricity balance increases the value of transmission capacity.

prise electricity producers, consumers, industry, system operators, etc. Any references to members of the Project Advisory Group will be spelled out explicitly.

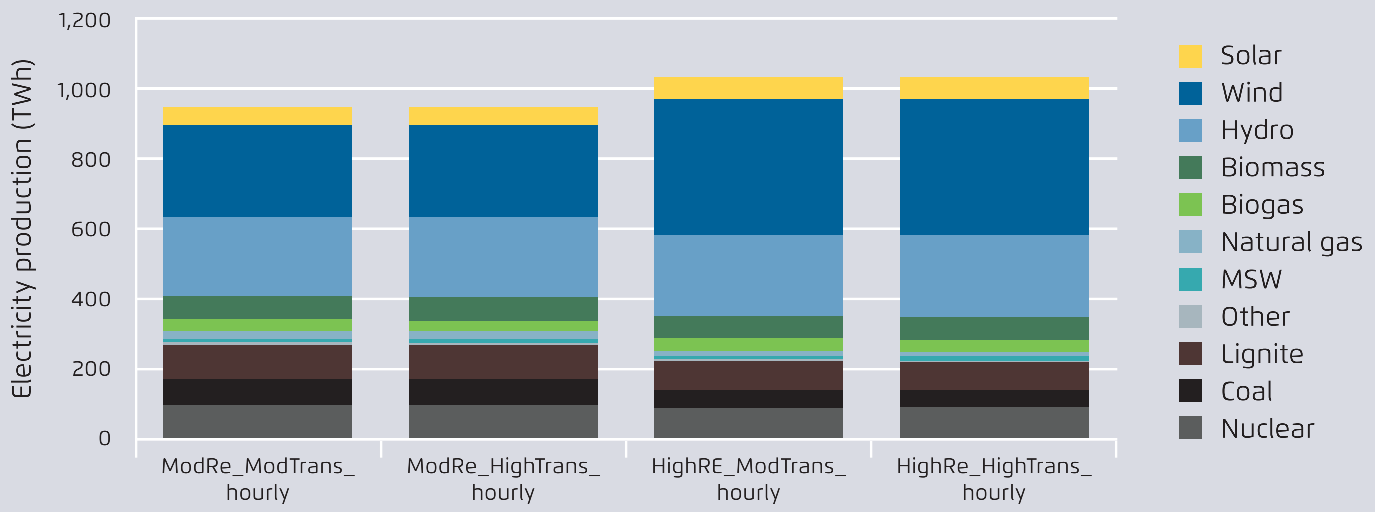
Assuming moderate renewable deployment (ModRE scenario), our modelling results show that almost 70 percent of total national production in the core countries will be based on renewable energy sources in 2030. Notably, around one third of all production will stem from *variable* renewable energy sources, that is to say, wind and solar (Figure 5). Note that run-of-river hydropower plants also have limited options for dispatching generation and can be regarded as variable to a certain degree. The Nordic system will remain dominated by hydropower, with a further 15 percent supplied by wind and solar. Strikingly, variable renewable energy sources account for half of German electricity production in this scenario.

In the High Renewable scenario, an additional 128 Terawatt hours (TWh) of solar and wind feed-in is part of the total generation mix in the core countries of this study, while nuclear power in Finland is reduced. Grid congestions lead to a small reduction of hydropower production (by 4 TWh), to less nuclear power production in Sweden and to decreased biomass-based power production in Denmark. In Germany, conventional generation declines by 47 TWh relative to the Moderate Renewable scenario. In total, higher renewable deployment leads to an overall increase in generation in the region by roughly 50 TWh.

A glance at Figure 5 illustrates another remarkable finding: the generation mix is only slightly affected by adding more transmission capacity, i.e., the extra 7.3 GW in the HighTrans scenario. Higher transmission capacity in the HighRE_HighTrans scenario has a somewhat limited effect compared with the moderate transmission case. Nevertheless, three salient yet moderately sized changes can be identified: fossil fuel-based power production in Germany is reduced by about 3 TWh; hydropower production in Norway increases by around 1.5 TWh; and biomass-fired power plants in Denmark increase production by 0.8 TWh. Hence, an increase in transmission capacity has only limited effect on the generation mix as such.

There is substantial potential for increased electricity trade between the Nordic countries and Germany relative to the situation today. More renewables are an important

2030 generation mix in the Nordic countries and Germany in four different scenarios. Figure 5



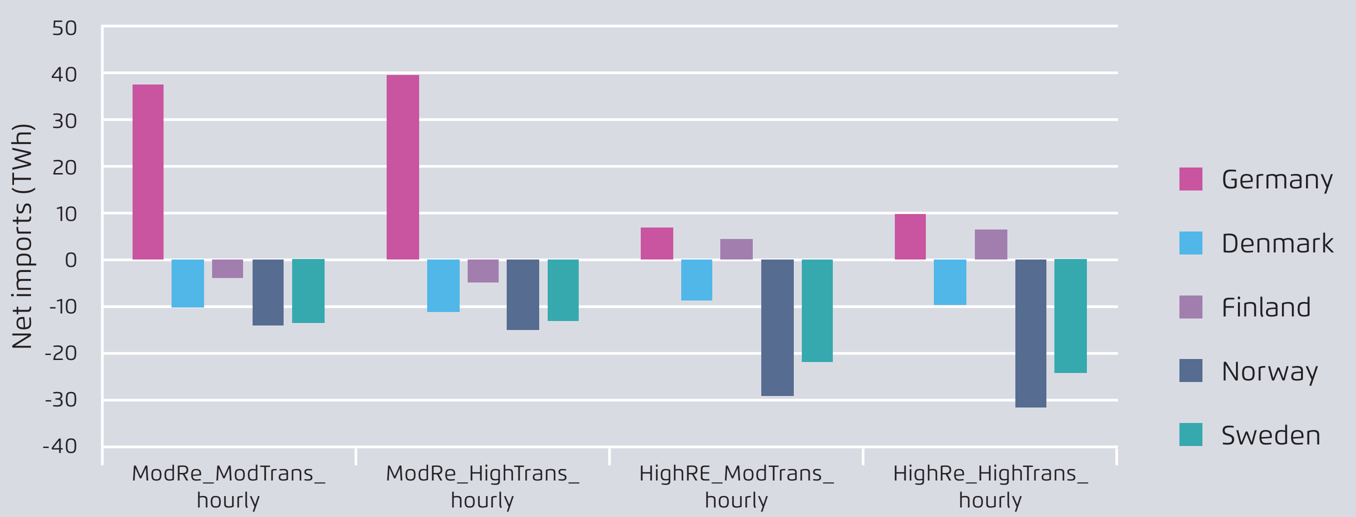
Ea and DTU, 2015

driver for the value of transmission capacity. On annual basis, power will be exported from the Nordics to Germany, but in reality trade patterns will be more complex, and will play an important role in balancing variable electricity production. In the Moderate Renewable scenarios, all Nordic countries are net exporters of electricity, with Norway and Sweden being the largest contributors at 13-14 TWh/year. In the High Renewable scenarios, export from Norway and Sweden increases to 51-56 TWh total. At the same time, export from Denmark remains stable at approximately 10 TWh/year, while Finland becomes a net importer due to lower levels of electricity generation from domestic nuclear power. Germany is a net importer of electricity in all scenarios, but the amounts are significantly reduced from almost 40 TWh in the Moderate Renewable scenarios to less than 10 TWh in the High Renewable scenarios.[3] This is due to the significant expansion of renewable energy in Germany. The electricity balance – in particular the high feed-in because of additional variable renewable generation in the Nordic countries in the High Renewable scenario – is a crucial driver for increasing the value of transmission capacity. As a region, Germany and the Nordic countries are a net exporter in all scenarios, ranging from 4 TWh/year in the Moderate Renewable scenarios to almost 50 TWh/year in the High Renewable scenarios.

The simulation of the hourly dispatch of the generators defines all flows between the regions. This is the basis for calculating the value of an additional Megawatt (MW) of transmission capacity. The marginal value of transmission capacity is equal to the absolute sum of the price spread, i.e., the price difference in individual hours between two regions. During hours with equal prices in two regions, there is no value of increasing transmission capacity. Table 3 clearly shows that the marginal value increases with increased deployment of renewables and decreases in the HighTrans scenarios where additional investments have already been made. The table also shows that there are considerable differences between transmission lines.

3 Note that in this study's HighTrans scenarios the transmission capacity between the Nordics and Germany increases, while interconnector capacities to the surrounding countries remain constant. In practice, the Nordic countries might as well build additional cross-border lines to other surrounding countries, such as the United Kingdom and the Baltic States, which could potentially reduce electricity imports to Germany. Other important factors determining the level of net import or export are national policies and the market configuration for conventional generation compared with neighbouring countries.

Net annual import to the Nordic countries and Germany in the four scenarios. Imports include those from other surrounding countries. Negative net imports correspond to exports. Figure 6



Ea and DTU, 2015

In general, higher transmission capacity leads to increasing market integration, and, hence, to higher average wholesale electricity prices in the Nordic countries and to lower prices in Germany. In the High Renewable scenarios, wholesale electricity prices are sharply reduced in the Nordic region relative to the moderate renewable deployment case. This relative price drop counteracts the price increase induced by more transmission capacity. In other words, even with more integration, the Nordic countries face no significant wholesale price increase if they deploy large shares of renewables themselves.

In the model, the wholesale electricity price is affected both by the level of renewable energy deployment and by the level of transmission capacity. The wholesale electricity price does not include any tariffs, taxes or levies, and thus does not represent the final price for consumers. In general, Northern Scandinavia shows relatively low wholesale electricity prices. An increase in transmission capacity leads to relatively higher average electricity prices in the Nordic countries and lower average prices in Germany. This price convergence reflects the fact that more electricity can be transmitted from the low price areas in the Nordic countries to Germany. However, the increasing price effect of more transmission lines for the Nordic countries is less pronounced than the price reducing effect obtained when more renewables (in particular, wind energy) is installed, especially in Norway and Sweden (High Renewable scenarios). As shown in Figure 7, the major determining factor for wholesale electricity prices is the level of renewable energy deployment. The greater price difference between the Nordic region and Germany in the High Renewable scenarios underlines the increased potential for electricity trade when more renewables must be integrated into the system. It should be mentioned, however, that depending on the national (or European) support scheme in place to promote renewables, even though wholesale prices drop with increasing renewables deployment, socialising costs as a means of financing them may still affect consumers.

The wholesale electricity price in each country varies considerably during the year, reflecting variations in demand, generation from variable renewable energy sources and hydropower reservoir influx. This variation can be shown by means of duration curves that give an ordered account of hourly prices over one year. In addition to the level of average electricity prices, the **hourly variation of the price**

Marginal value of transmission capacity for the transmission lines with higher capacity in the High Transmission scenarios. The cost estimates are based on data from the TYNDP 2014 with an interest of 4 per cent and a 30-year lifetime. Operation and maintenance cost as well as cost of losses are not included. Table 3

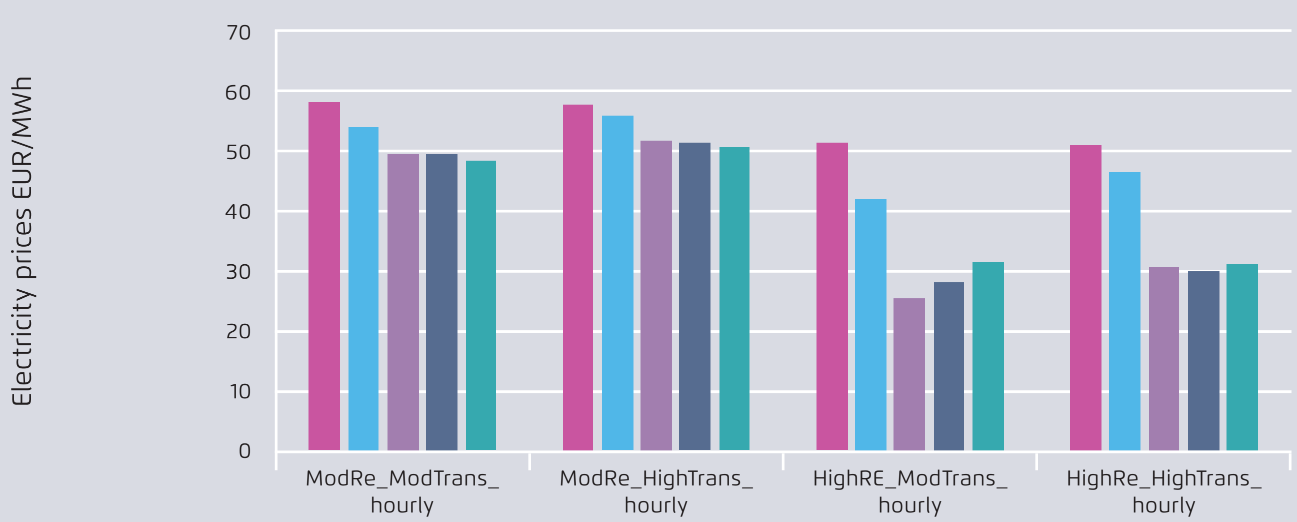
				Marginal value of transmission k€/MW			
From	To	Capacity* (Additional) MW	Cost k€/MW	ModRE ModTrans	ModRE HighTrans	HighRE ModTrans	HighRE HighTrans
DK_W	DE_NW	2,500 (500)	20-24–	32	17	74	42
SE_S	DE_NE	0 (700)	17-33–	90	74	206	185
SE_N1	FI_R	1,300 (1.000)	4-7	8	1	45	21
NO_N	FI_R	0 (500)	35 - 81	-**	12	-**	53
NO_N	SE_N2	275 (750)	11 - 25	32	13	86	33
DK_E	DE_NE	600 (600)	48-59	48	17	110	44
SE_S	SE_M	4,850 (700)	14-22–	3	3	5	8
NO_M	NO_N	600 (1.200)	42 - 72	20	5	42	10
DK_W	DK_E	600 (600)	38-46–	18	1	39	4
SE_M	SE_N2	8,000 (700)	66-116	9	6	20	19

*Capacity shown for Moderate Transmission scenarios for 2030 and additional capacity in High Transmission scenarios for 2030. ** Marginal value is not shown if the transmission line does not exist in the respective scenario; Ea and DTU, 2015

spread between two regions is the major determinant for the potential of electricity trade. Two regions can have a large trade potential even if they have the same annual average price level, provided that high and low prices occur at different hours. Figure 8 illustrates the duration curve of the price spread between Southern Norway and Germany. In the Moderate Renewable scenarios prices are lower in Norway for around 6,200 hours; in the High Renewable scenarios, they are lower for some 7,000 hours. This implies the main flow direction is from Norway to Germany. The connection between the two countries is mainly used for exports from Norway to Germany, and to a lesser extent for exporting German wind power surplus to Norway. Note that the duration curve for the price spread between Germany and Sweden would show the same shape, but with a slightly higher number of hours with lower prices in Sweden. Importantly, the wholesale electricity price is only a part of the final electricity price to be paid by consumers. The final price includes additional costs such as taxes, levies and distribution fees. This, along with distributional effects, will be touched on later.

The deployment of additional renewables in the Nordic countries and in Germany leads to a significant reduction in CO_2 emissions. While the emissions effect of additional transmission capacity itself is limited, an increase in transmission capacity constitutes a prerequisite for higher renewable integration.

Average annual wholesale electricity prices. Wholesale price level for countries as a simple average across regions. (Note that wholesale electricity prices are not consumer prices, which include additional costs such as taxes, levies and distribution fees). Figure 7



	ModRe_ModTrans_ hourly	ModRe_HighTrans_ hourly	HighRE_ModTrans_ hourly	HighRe_HighTrans_ hourly
Germany	58	57	51	51
Denmark	54	56	42	46
Norway	49	51	25	30
Sweden	49	51	28	30
Finland	48	50	31	31

Ea and DTU, 2015

A closer integration of the Nordic and German electricity systems leads to a reduction of total CO_2-emissions due to better utilisation of renewables (both in terms of their potential and their capacity) as a result of four factors:

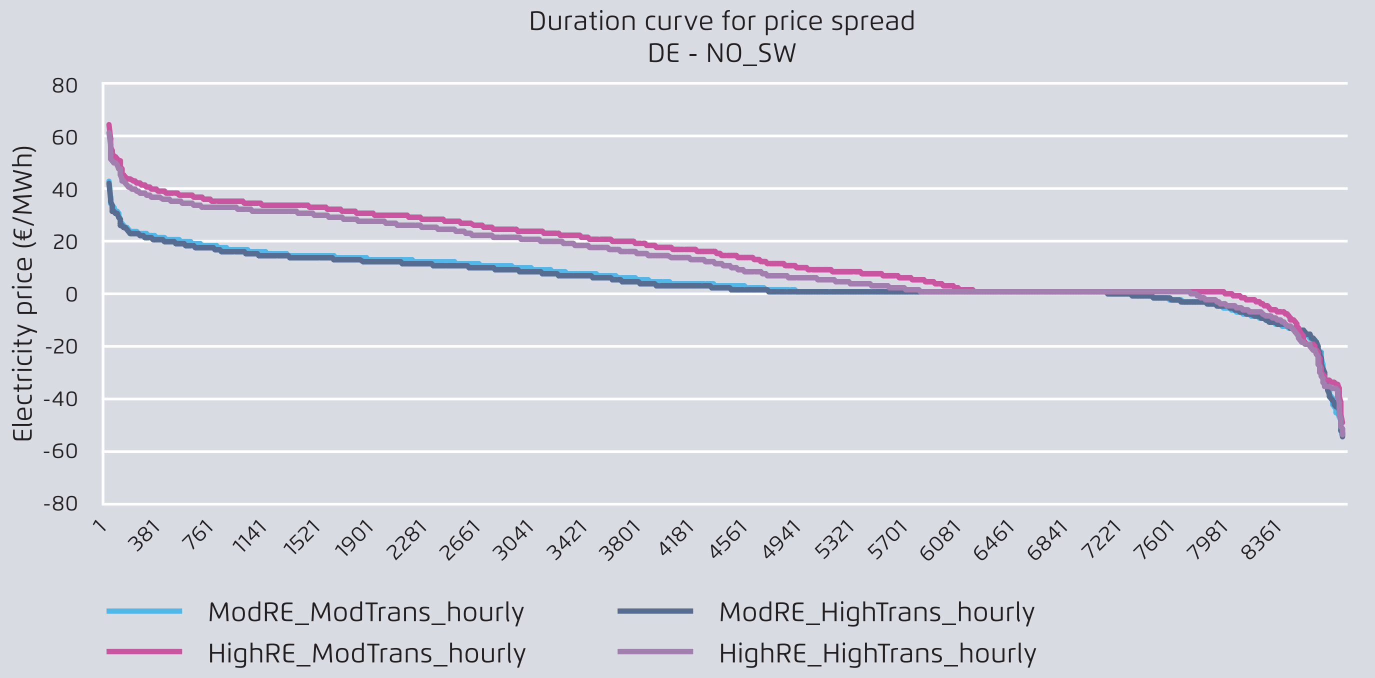
- → Reduced curtailment (of hydro and wind power), and hence higher CO_2 free renewable feed-in.
- → Improved options for choosing regions (e.g., those with favourable wind resources), including domestic network integration (so-called "hinterland integration") with stronger grids inside the countries (e.g., in Norway and Sweden).
- → Increased competitiveness of biomass-fuelled power plants due to better market integration.
- → Increased investments in renewables from an overall system perspective (though these are not quantified in the current study, the High Renewable scenarios indicate large wind potentials in the Nordic countries).

The deployment of electricity from renewable resources in the Nordic countries and in Germany will lead to a significant reduction of CO_2 emissions by 2030.[4] The reduction amounts to 40 to 55 percent as compared to the 2013 level in the electricity and heat sector (Figure 9). These CO_2 savings are not nullified by increasing CO_2 emissions in surrounding countries. This means that emissions from

4 This study assumes a fixed price for CO_2 to set a value on greenhouse gas emissions. The price is based on the New Policies Scenario of the IEA World Energy Outlook (2013). Effects related to the European Emissions Trading System (ETS) have not been analysed. Since this study analyses the effect of physical changes in the power system, not policies affecting CO_2 emissions, a fixed CO_2 price was used.

Price spread between Southern Norway and Germany in the four scenarios. Positive values indicate a higher price in Germany than in Norway. The duration curve for the price spread between Germany and Sweden would show the same shape, but with a slightly higher number of hours with lower prices in Sweden.

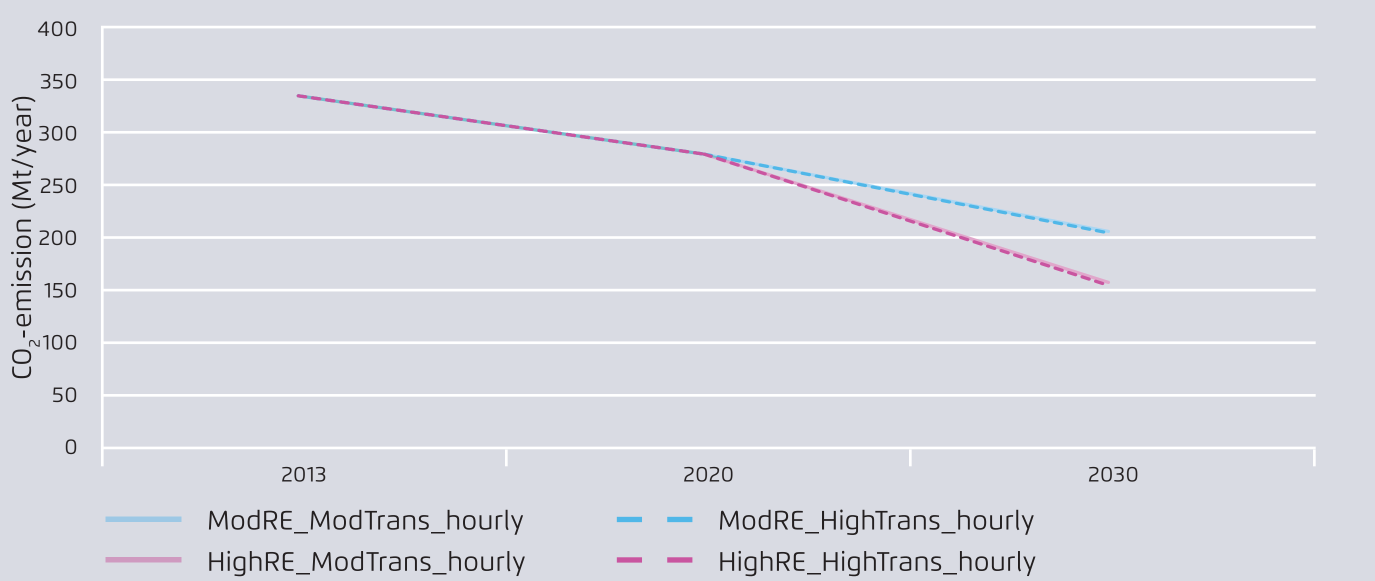
Figure 8



Ea and DTU, 2015

CO_2 emissions in the Nordic countries and in Germany in the four scenarios.

Figure 9



Ea and DTU, 2015

CO_2 savings from additional transmission capacity. Table 4

	Moderate RE		High RE	
	Mt/year	%	Mt/year	%/year
Nordics + Germany	-1.5	-0.7%	-3.3	-2.1%
Surrounding countries	-0.3	-0.1%	-1.5	-0.5%
Nordics, Germany and surrounding countries	-1.8	-0.3%	-4.9	-1.1%

Ea and DTU, 2015

fossil fuel-fired power plants are not displaced to other countries, i.e., they are actually avoided. In the Moderate Renewable scenarios, additional CO_2 savings can be particularly attributed to increased power production from biomass in Denmark and higher wind power production in Norway. In Norway increased grid integration comes with the option of locating wind power capacity further north, where wind conditions are better. The same effect in terms of optimal siting exists for Sweden and Norway in the High Renewable scenario. As a result, the total CO_2 reduction effect is even larger when adding transmission capacity in the High Renewable scenario.

The direct extra effect of additional transmission capacity on CO_2 savings is limited (Table 4). In the High Renewable scenario, the direct CO_2 reduction from increased integration amounts to 2.1 percent of total emissions within the region. This shows again that additional renewable deployment is the main factor for achieving high emissions reductions. Yet, increased interconnectivity of the grids can be regarded as a prerequisite for higher investment volumes in renewables, which in turn lead to emission reductions. Also, it should be noted again that interconnectors are predominantly built for the achievement of other benefits associated with increased integration. Still, to strengthen investor confidence in deploying renewable generation, adequate grid capacity is needed for feed-in from new production units.

Levels of redistribution are significantly higher across different stakeholder groups within *one* country than distributional effects are between countries. Additional integration leads to price convergence between higher and lower price countries. In general, producers benefit in countries with increasing prices (the former "lower price countries") and consumers in countries with decreasing prices (the former "higher price countries"). In the Nordic countries, hydropower and wind generators gain the most, while consumers face higher electricity prices than with moderate grid integration. In Germany, consumers benefit from lower prices, whereas producers mostly incur losses. At the country level, Norway and Germany stand out, each showing high benefits from increased integration in the case of moderate renewable deployment. Under high renewable deployment, these outstanding effects can be found in Norway and Sweden.

Increased integration affects the market outcome and thereby alters rents of electricity generators, network operators and power consumers – the so-called stakeholder rent. These distributional integration effects determine who actually pays and collects benefits from increased integration. The aggregated change in rent for all stakeholders within one country shows the extent to which a country benefits or incurs losses from increased integration.

Broadly speaking, distributional effects materialise along two dimensions:

→ across countries or regions, and
→ across stakeholders within one country, that is, across residential and industrial consumers, and across transmission and generation companies.

In order to determine the total benefit for each country, changes in stakeholder rents are aggregated at the national level. Notably, the Nordic power market is smaller in size and less integrated in neighbouring systems. Thus, additional transmission capacity has stronger effects on Nordic prices.

In total, rents increase for both grid integration scenarios, yet more so for the high renewable case (Table 6). Table 5 and Table 6 show the change in welfare arising from increased grid integration in the Moderate and in the High Renewable scenario, respectively. For each of the two Renewable scenarios, they indicate whether stakeholder rent has increased or decreased in the HighTrans scenario relative to the ModTrans scenario.

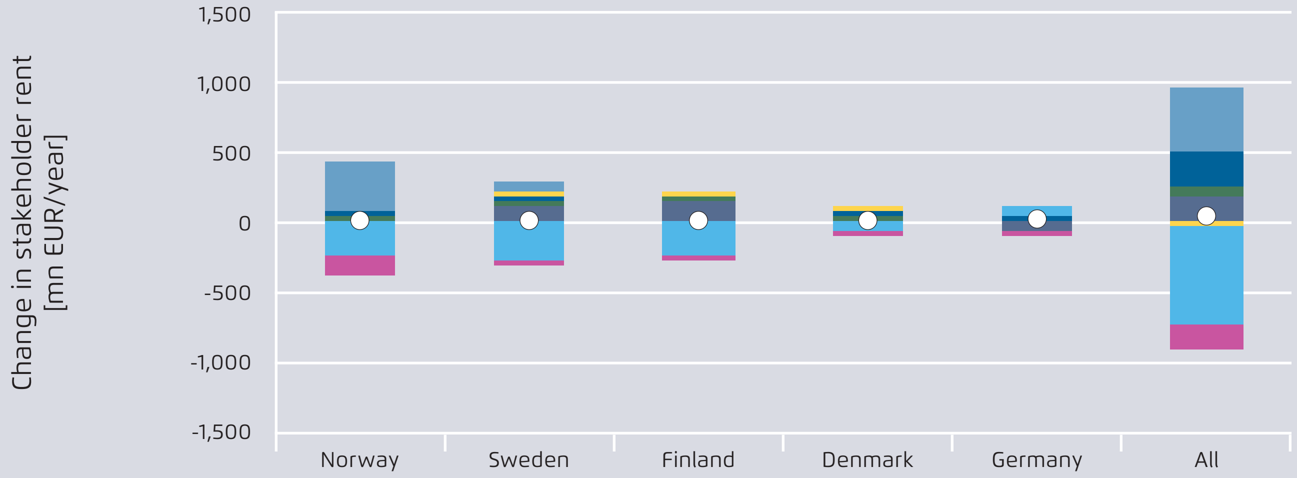
In the **Moderate Renewable scenario** (Table 5), the **distributional effects** are strongest within the **Nordic countries**. Due to higher average prices, Nordic hydropower producers earn an additional 450 million euros; Nordic wind power producers an additional 190 million euros. Overall, the major beneficiary is Norwegian hydropower production. Gains for wind generation are allocated more evenly across the Nordic countries. In Denmark, wind energy producers are the biggest beneficiaries of increased transmission. Consumers in the Nordic countries, by contrast, face an increase in their electricity payments by more than 750 million euros due to higher wholesale electricity prices. For Germany, the reverse situation prevails, with consumers gaining and producers losing stakeholder rent. However, distributive effects are fairly moderate compared with Nordic countries. Interestingly, the only case where German producers benefit from increased integration is wind power, indicating better integration of variable generation and thus a higher value for wind power.

At the **country level**, the greatest beneficiaries of increased integration in the Moderate Renewable scenario are Germany and Norway, followed by Sweden. By contrast, Denmark and Finland incur overall losses. This can be mainly attributed to the higher costs paid by consumers as a result of higher wholesale electricity prices. Nevertheless, it is important to point out that the incurred welfare losses for Denmark and Finland are still very limited (e.g. five million euros p.a. in the case of Denmark).

In the **High Renewable scenario** (Table 6), the effects become even more apparent in numerical terms. Yet the findings vary somewhat at country and stakeholder levels. **Distributional effects** are primarily driven by cumulative increases in rents for wind power and hydropower generators in the Nordic countries. Again, hydropower producers in Norway obtain the largest rent increase at the national stakeholder level (730 million euros, as compared with 336 million euros in the Moderate Renewable scenario). At the same time, integration triggers decreasing profits for all German producers (now, in contrast to before, including wind power). Higher renewable shares imply more imports of surplus generation from the Nordic countries. Consumers in Finland, a net importer under the High Renewable scenario, benefit from integration. But producers in Finland lose profits in all areas except wind power. This is a reverse situation to the moderate renewable case, where all of Finnish production benefitted from increased integration (except for PV with no change in rent at all). Redistribution levels from consumers to producers are highest for Norway (900 million euros), followed by Sweden (300 million euros) and Denmark (150 million euros). With the exception of nuclear producers in Sweden (whose increased profits amount to 100 million euros), renewable producers collect most of the increased rents (mainly from wind and hydropower).

At the **country level**, Germany benefits less from integration in the High Renewable scenario as compared to the moderate renewable case. The largest welfare increase accrues to Sweden, followed by Norway. Finland also receives a positive national rent from integration in the high renewable case, whereas it incurs a slight loss in welfare in

Distributional integration effects at the stakeholder level in Moderate Renewable Scenario (ModRE_HighTrans as compared ModRE_ModTrans). The change in stakeholder rent is indicated for consumers, producers, transmission system operators (TSOs) and the total country in total. Positive values indicate welfare gains derived from increased transmission capacity. Table 5



	Norway	Sweden	Finland	Denmark	Germany	All
Congestion rent	-128	-9	-1	-17	-10	-165
Consumers	-233	-250	-219	-63	91	-673
Hydro power	336	92	28	0	-4	452
Photovoltaic	0	0	0	1	-5	-4
Wind power	59	49	29	55	13	204
Biomass	0	27	34	15	-12	64
Conventional	1	103	128	5	-50	188
Total country	35	12	-1	-5	34	75

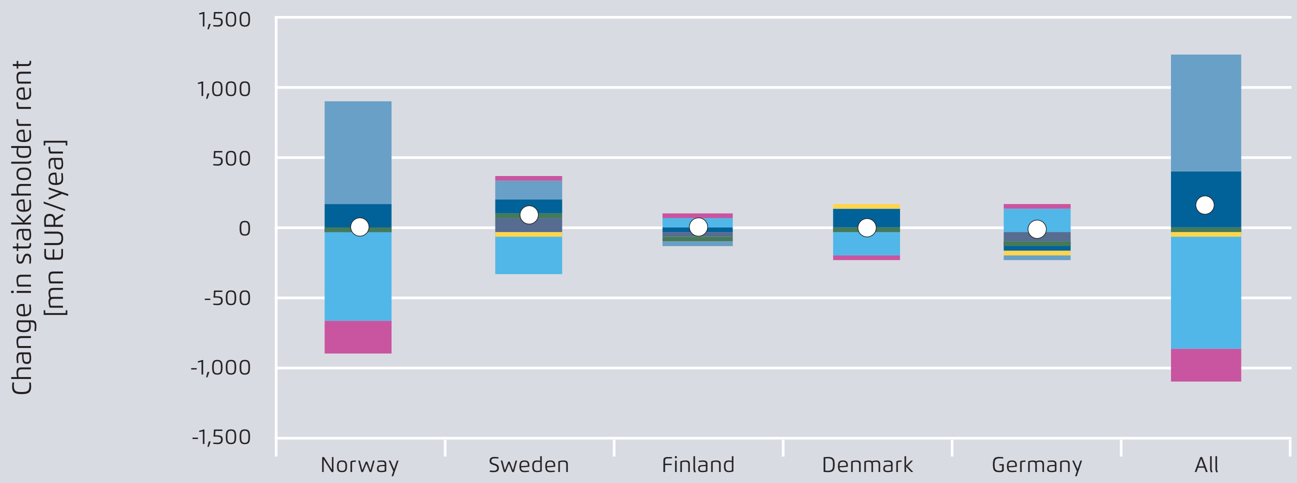
DIW, 2015

the Moderate Renewable scenario. Denmark sees an incremental increase in national rent, mostly attributable to the high gains by Danish wind production.

Seasonal hydro storage in Norway and Sweden is often considered one of the main drivers for integration due to its flexibility, allowing it to compensate for wind generation fluctuations in the North Sea and Baltic Sea regions. Stronger integration provides opportunities for trade in both directions. Wholesale electricity market price results do not indicate clear additional benefits from integration for hydro storage. In the Nordic market, the added transmission capacity supports the integration of increased wind power, which receives a higher than average price increase. Hydropower in Norway and Sweden is in line with the average price increase while conventional generation receives less than average benefits, especially in the High Renewable scenario. In Germany, differences to the already moderate price effects are very small when integration increases.[5]

5 The economic effects may be different for hydropower when annual inflow variations in Nordic hydropower are taken into account. The full effect is not reflected in the present study, which relies on an annual average for hydro production. The benefits – in the form of decreased total system costs – do not cover all the possible aspects of increased value from increased transmission ca-

Distributional integration effects at the stakeholder level in the High Renewable scenario (HighRE_HighTrans relative to HighRE_ModTrans). The change in stakeholder rent is indicated for consumers, producers, transmission system operators (TSOs) and the country in total. Positive values indicate welfare gains derived from increased transmission capacity. Table 6



	Norway	Sweden	Finland	Denmark	Germany	All
Congestion rent	-262	49	5	-24	2	-229
Consumers	-615	-294	71	-154	170	-821
Hydro power	730	128	-22	0	-8	829
Photovoltaic	0	-1	0	2	-15	-14
Wind power	199	89	16	146	-68	381
Biomass	1	36	-14	24	-14	34
Conventional	0	107	-47	7	-58	10
Total country	54	115	10	1	10	191

DIW, 2015

In conclusion, levels of redistribution are significantly higher across stakeholder groups than welfare effects between countries. At the national level, price convergence creates winners and losers among consumers and producers. Generally, additional integration benefits producers in countries with increasing prices and consumers in countries with decreasing prices.

The assessment of benefits and costs from higher integration relies on an energy-only market model. The different levels of network investment have entered the analysis as exogenous scenario assumptions. Generally, there are three types of transmission line investments: cross-border lines (connecting two countries), cross-zonal lines (connecting two price zones within one country) and intra-zonal lines. The first two types are explicitly addressed in the scenario definitions; the last type can be necessary to facilitate further integration.

pacity. The sharing of balancing reserves across regions, increased (or more affordable) security of supply and better options for handling variable generation from RES-E can influence (and are likely to increase) the value of increased transmission capacity. The last aspect – handling variable generation – is especially important for hydro dominated countries, such as Norway, where the inflow to hydropower plants can differ significantly from year to year. The effect of these variations has not been subject to detailed analysis within this study; it is mentioned here only as a topic for further research.

As such, all lines are subject to specific investment costs that must be allocated among the involved parties. For lines connecting two countries, one can assume a simple sharing rule whereby costs are equally distributed across the directly involved countries. But other schemes are possible as well. The difficult question that needs to be assessed is who actually benefits most from the integration triggered by an interconnector. This is vital to arrive at a sound and incentive compatible solution. Lines between two price zones within one country can basically be regarded as national projects. Beyond a facilitated spatial equalisation of supply and demand, integration of renewables or enhanced security of supply within one country, however, they are also part of integrating a larger region. Intra-zonal lines are not explicitly taken into account, and price zones are treated as copper plates. They are nevertheless implicitly important for the hinterland integration of cross-border interconnectors to accommodate altered flows due to new import or export possibilities. At the same time, as with cross-zonal lines, it is difficult to disentangle the share of internal line upgrades used predominantly for hinterland integration from other ends as aligning a spatially changing generation pattern with demand or network security considerations.

The allocation of transmission investment costs, therefore, raises further distributional questions. National strategic behaviour could hamper further integration. But the analysis shows that overall net benefits on the energy-only market are positive. This means that prudent cost allocation schemes can facilitate reaping integration benefits overall.

The impact of prices on individual stakeholders, such as specific consumer groups, depends on final electricity prices. In addition to energy and supply costs, the latter may include network costs, taxes and other levies. Energy-intensive industries in the Nordic countries are most directly exposed to increased electricity prices.

For large and energy-intensive industrial customers, the cost of electricity supply is mostly driven by the electricity price on the wholesale market. Current prices support energy-intensive industries, with the dominant cost element being wholesale electricity prices: these industries are mostly exempted from other charges that are socialised among other consumers. For small and medium enterprises – as well as those that are not energy intensive – taxes and levies play a bigger role, as they are typically not exempted from other charges. Countries with low electricity prices generally have a competitive advantage and may thus attract energy-intensive manufacturers. Especially in the Nordic countries, energy-intensive industry has historically benefitted from low electricity prices. The main component of electricity prices for electricity-intensive industry in Sweden, Norway and Finland is the cost of electricity on the wholesale market. Therefore, varying electricity prices will have a non-negligible impact on the cost structure of those branches in relative terms. At the same time, more renewables drive down electricity prices on the wholesale market. The grid tariff, taxes and levies are comparably low. (Taxes in Sweden, for example, are below one Euro per MWh.) There is some, but not considerably much, leeway for policy to accommodate these changes in the energy component of electricity prices. For industrial consumers, investments in energy efficiency would provide some means to mitigate increasing electricity prices. This could yield a "double-dividend" effect through more energy efficiency: by reducing electricity costs while decreasing total demand, energy efficiency can exert a downward pressure on prices.

Further integration of the Nordic and German electricity systems would lead to a moderate increase in electricity prices. However, the effect is only limited. Importantly, and as pointed out before, wholesale electricity prices in the Nordics increase with integration, but decrease with renewable deployment. This means that high renewable deployment in the Nordic countries may mitigate the negative consequences of certain price effects that would otherwise negatively affect Nordic industries. For the price impact on residential and industrial consumers, the applicable financing support schemes for renewables are crucial. If energy intensive industry is exempted from a renewable surcharge, or any similar financing component for promoting renewables, then the wholesale electricity price will be the primary driver for the cost of electricity supply. The situation is different for consumer groups where such exemptions do not apply, and that have to bear part of the cost for socialising renewable energy support, especially when RES-E deployment is high. For those consumer groups, it may not be the wholesale electricity price that is the primary driver of their final price, but also the costs for socialising renewable support.

E. Conclusions and Outlook

Objectives and forecasts for the Nordic countries and Germany anticipate substantial amounts of renewables in electricity supply through 2030. Germany aims for a share of 55 to 60 percent of renewables in final electricity consumption by 2035 as part of its "Energiewende", or green energy transition. Denmark even plans to establish an electricity and heat supply entirely based on renewables by that time. Sweden has yet to define a national renewable energy objective for 2030, but it contains large untapped potentials for wind energy.

A multitude of drivers will influence the pace and volume of the future increase in renewable energy sources across countries. At the same time, integrating rising shares of renewables will become increasingly challenging because national systems were built and dimensioned based on assumptions relevant 40 to 50 years ago. If measures are not taken at an early stage, existing system design will prevent the growth of variable renewable energy sources. Due to their age, electricity systems in the Nordics and in Germany are up for renewal. To increase system flexibility, forward-looking designs are needed. Grid expansion and cross-border interconnectors are important flexibility options for enabling cross-border system balancing for the integration of variable renewable electricity generation across larger regions.

In our study, we have analysed some of the challenges lying ahead by defining four scenarios and using them as a base for quantitative and qualitative analysis. We have arrived at several main conclusions:

- → There is great potential for electricity trade between the Nordic countries and Germany. This is due to the differences in hourly wholesale electricity prices between the two regions. Additional volumes of electricity based on renewable energy sources increase the value of additional transmission capacity between the Nordics and Germany.
- → More cross-border integration can play an important role by levelling out variations in generation and lowering total cost.
- → The grid expansion envisaged by our High Transmission scenario and the grid projects of the TYNDP 2014 for 2030 is beneficial provided renewable deployment remains high (High Renewable scenario). An optimisation of grid expansion could improve total welfare (with total system benefits outweighing additional infrastructure costs). The Moderate Renewable scenarios indicate that a different set of transmission capacity expansion could be more beneficial than with our high transmission assumptions. Under a different set of transmission expansion, also in the moderate renewable case grid expansion could yield benefits resulting from total system cost reductions.
- → Higher integration leads to convergence of wholesale electricity prices. This creates distributional effects across countries and across stakeholders within countries. In general, additional integration benefits power producers in countries with increasing wholesale electricity prices relative to moderate integration (the Nordics) and electricity consumers in countries with decreasing prices induced by price convergence (Germany).
- → There are significant distributional effects impacting incentives for different sorts of market players. As price changes are asymmetric, integration triggers an uneven redistribution already at the country-level. 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. Distributional effects

need to be taken into account for creating public acceptance for new lines and for the cross-border allocation of network investments.

- Competitiveness of energy-intensive industries is a sensitive issue of national industrial policy. Today, industrial electricity prices are considerably lower in Sweden, Norway and Finland than in Denmark and Germany. Distributional effects for industrial customers are thus expected to affect industry branches differently depending on the country. A better understanding of the ramifications of stronger integration will help shape targeted policy measures.
- A closer integration of the Nordic and the German power systems will reduce CO_2 emissions due to better utilisation of renewable electricity. This is caused by less curtailment of renewables, improved integration of additional renewable production sites and the increased competitiveness of biomass-fuelled power plants.

National strategic considerations and stakeholder opposition can undermine interconnector projects and hamper cross-border system integration, which generally benefits regional electricity markets. Distributional effects (price convergence and asymmetric allocation of costs and benefits) introduce a political dimension to the "economy of interconnector investment". The political dimension has a clear "being good neighbours" element: prudent cost allocation schemes can facilitate the overall benefits of integration. By building common solutions, win-win situations can emerge. In a long run, what is important is total value creation, not just the costs. Overarching goals, such as the completion of the European energy market and security of supply, need to be taken into account when discussing the total value of increased integration. We need continued regional dialogue across stakeholders and countries about cost sharing, incentives and future ambitions.

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