Nordic Grid Development Plan 2019

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Content

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Executive summary

The Nordic power system will continue to change rapidly towards 2040. Demand in the Nordic power grid is growing due to new kinds of electrification and new types of demands. The generation portfolio is changing, with the amount of renewables growing rapidly, and conventional generation being phased out. Renewables are also growing today without subsidies, which makes it harder to predict which projects will become a reality. Also, the supply-demand balance will change in the future as new generation is built further away from the centres of demand.

A stronger grid enables new renewable generation to enter the market and replace generation from fossil fuels, thus contributing to a fully fossil-free generation portfolio. Furthermore, it may support other sectors, such as the transport sector and steel manufacturing, to electrify and become less dependent on fossil fuels, and thus reduce greenhouse gas emissions.

In this report Energinet, Fingrid, Statnett and Affärsverket svenska kraftnät (Svenska kraftnät) present a common view on the overall development of the future power system and the status of ongoing and planned investments of Nordic significance. In addition, we present an early outlook for possible future grid investments in five Nordic corridors, revealing a potential to further strengthen capacity between the Nordic countries.

Large grid and market portfolios cover the needs in the medium term

The Nordic TSOs all have large portfolios of ongoing and planned grid development projects. In total the Nordic TSOs plan to invest more than EUR 15 billion until 2028. This increases the overall transmission capacity, reduce bottlenecks in the system and make it possible to integrate large amounts of new renewable production, primarily wind power.

In parallel, as described in "The way forward – Solutions for a changing Nordic power system"[1], different measures are implemented to make the market and system operation more effective. Datahubs are being developed in all the countries, the power market is moving towards shorter timeframes, solutions to respond to the diminishing inertia in the system are being implemented and new ways to balance the

[1] https://www.svk.se/siteassets/om-oss/rapporter/2018/the-way-forward---solutions-for-a-changing-nordic-power-system.pdf

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system are being introduced. Together with the ongoing and planned grid development, this covers most of the system needs in the medium term, towards 2025–30.

Volatility drives up the long-term benefit of interconnectors
An increasing volatility in production and power prices is driving up the long-term benefit of interconnector capacity within the Nordic area. The five corridors analysed for this plan all have higher benefits in the 2040 situation compared to 2030. This is linked to the increase of renewable generation and the reduction of conventional thermal and nuclear generation capacity. In addition, a higher CO_2 price and more volatile continental power prices are drivers for increased price differences across borders, thus increasing the benefits of interconnector capacity.

The different geographical location of the renewable production compared to the nuclear and thermal capacity it replaces is another driver for further grid development. The phased-out production capacity is located in the southern part of the system whereas a significant share of the wind power replacing it will be located in the more northern parts. This creates more long-distance power flow in the system and contributes to congestion in the transmission grid, with lower power prices in the northern part. The prices in the southern part will be higher and more connected to the continental prices.

The development of various sources of flexibility is important to realise the benefit of new grid investments in the long term towards 2040. The development of end-consumer flexibility, flexible industrial consumption and large-scale batteries are likely to curb price fluctuations and decrease the need for interconnectors. However, this is a highly uncertain driver depending on future technological development.

The analyses made for this plan indicate a long-term need and the socioeconomic benefit of both maintaining and expanding the interconnector capacity within the Nordic system. However, there are significant uncertainties. It is possible that intermittent production will develop faster than in the scenario presented. Thus, the system may reach a situation of high benefits, as in the 2040 estimation, at a much earlier stage. On the other hand, there may be developments that reduce the need and benefit of new grid investments, e.g. the TSOs are active in the development of other solutions within the market and system operation.

The system is getting more complex and integrated
The power system is getting more complex, both to operate and to analyse. Key drivers for this are the higher share of intermittent generation, the phaseout of conventional generators, more control systems interacting, as well as frequency and voltage support decreasing. Furthermore, as the system becomes more interconnected, the impact of areas outside the Nordics becomes more prominent. An example of this is the increasing importance of the German north–south bottlenecks in the studies of Nordic interconnectors.

With the power system changing, the role of grid reinforcements in maintaining and improving system adequacy is becoming increasingly important. From this perspective, a major challenge for the future is the role and market design of flexibility and storage. A more complex system will also be more challenging to operate. This makes the ongoing development of the market design and system operation even more important.

Nordic grid plans and studies will be updated and developed
The Nordic Grid Development Plan will be updated every second year, as part of the larger cooperation described in the report "The way forward – Solutions for a changing Nordic power system". The next plan will be published 2021. It is the ambition of the Nordic TSOs to further improve the cooperation on both grid planning and studies.

Updated scenarios for market development, the overall need for more grid capacity north-south in the whole Nordic region and more interconnector capacity are all relevant topics in the next plan.

Another issue which needs regional cooperation is study of security of supply. Stronger grids and increased trading capacity between countries may improve the situation, but there must also be available generation capacity or consumer flexibility that can provide the needed peak power. It is a regional challenge to analyse what potential there is for countries to support each other in situations of scarcity. Such an analysis was performed earlier and presented in the report "Nordic perspectives on mid-term adequacy forecast 2017".[2]

[2] https://www.svk.se/siteassets/om-oss/rapporter/2018/nordic-perspectives-on-maf.pdf

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2 Introduction

Energinet, Fingrid, Statnett and Affärsverket svenska kraftnät (Svenska kraftnät) publish a common Nordic Grid Development Plan (NGDP) every second year, by request of the Nordic Council of Ministers. The purpose is to communicate a common Nordic view on the overall development of the future power system, the status of ongoing and planned investments of Nordic significance, and how the investments contribute to Nordic socioeconomic welfare. In addition, NGDP2019 presents key points from a set of bilateral analyses, exploring the potential of new investments in five corridors identified in NGDP2017.

The NGDP is intended to function as a complementary bridge between the national planning processes and the ENTSO-E Ten Year Network Development Plan. This is especially true for the analysis of the selected corridors, where the ambition is to present a comprehensive overview of the net benefits of increasing the transmission capacity, describe the main drivers and provide an assessment of the uncertainty of possible future investments. However, it is important to recognise that it is early stage analysis made to see if there is a potential for further investigation and not a complete basis for investment decisions. The exception is the corridor Sweden-Finland where the process has been ongoing longer.

An important part of the work has been to prepare a common Nordic reference scenario with data sets for use in each TSO's market models. The data sets are used as a starting point for the bilateral analyses, and the work on the data sets was mainly carried out in the autumn of 2017 and in the beginning of 2018. This work was based on the scenario Sustainable Transition from ENTSO-E. One scenario with two sets of data were developed, one for 2030 and one for 2040.

There are several challenges recognised by Nordic TSOs, for example diminishing inertia and changing adequacy situation. This report is not trying to analyse these aspects, although they have been recognised, instead the main focus is on grid development.

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Main direction and drivers for grid investments

The Nordic power system is likely to undergo major changes towards 2040. Consumption is increasing, mainly as a result of new data centres, electrification of transport, heating and different types of industry processes. In parallel, the growth in renewable power production will continue, largely in form of wind power but also through solar power. The total capacity of more controllable power production will decrease, including nuclear power and other types of thermal production. As a result, less controllable and highly weather-dependent production will become dominant towards 2040. All the Nordic countries also experience local adequacy issues with power supply to city areas due to a combination of aging grid, consumption growth and closure of local generation plants. These provide several challenges for the whole system and are described in the report "The way forward – Solutions for a changing Nordic power system". In addition, it increases the need for grid investment, together with other important factors:

- Future continental power prices – and thus prices of gas, coal and CO_2
- Age and need for reinvestments in existing grid assets
- Security of supply
- The increasing capacity between the Nordic and the continental system

Normally, grid investments are driven by a combination of different factors. In the longer term, there is uncertainty in both the drivers and how they affect grid development.

Strengthening of the grid improves the security of supply and eliminates bottlenecks. It is not, however, socioeconomically beneficial to invest in grid capacity to eliminate all hours with price differences. It is therefore desirable that market solutions evolve to complement grid capacity investments in managing the supply-demand balance.

3.1 Electrification and new industries drive consumption growth

The total Nordic power consumption has been stable during the last ten years. However, now there seems to be a trend shift. Despite a continuous focus on energy efficiency, consumption is likely to increase over the coming years. The main drivers for this are the

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electrification of transport and petroleum industries and higher consumption related to wood processing, data centres and steel production.

It is increasingly clear that we are moving towards a significant electrification of the transport sector. Lower battery costs and stricter vehicle emission regulations are important reasons for this. The total volume of electric vehicles is still quite low at a Nordic level, with Norway being ahead of the other Nordic countries. In March of 2019, close to 60 per cent of all new cars sold in Norway were electric vehicles (EVs), and with most of the main manufactures now developing new types of electric cars, the main uncertainty is not "if" but "when" the sale of EVs will take off in the rest of the Nordic countries. In addition, there is likely to be an increased electrification of busses, local ferries and other types of transport.

Data centres is a growing sector which seems to value the Nordic region for its low power prices, a high level of security of supply, good infrastructure and a cool climate. Over the last few years, there has been a sharp increase both in the number of planned data centres and the number of units being built. This will definitely contribute to a considerable increase in power consumption. However, a large possible growth makes the overall future consumption from this industry highly uncertain. Further, the exact locations of these new consumption units are even more uncertain.

Electrification of transport is primarily a driver for local grid investments, whereas larger consumption units such as data centres may trigger both regional and national grid investments. On the other hand, growth in power consumption in itself seems to be a more moderate driver for increased transmission capacity between countries. However, indirectly and together with other drivers, it might be important.

3.2 Reduced nuclear and conventional units

Nuclear power plants are of great importance nationally in Sweden and Finland, but also for the entire Nordic power system. With steady and predictable generation close to consumer centres, nuclear power contributes to security of supply, stable market prices and maintaining system stability in the Nordic power system. While Finland continues to focus on nuclear power and plans to retain its capacity, Sweden has currently no plans to build new nuclear reactors when existing reactors are finally decommissioned. Although the exact timing of decommissioning is uncertain, it is clear that a full phaseout will have a major impact, especially for the south of Sweden but also for the whole Nordic region.

Several fossil-fuelled plants have already been decommissioned due to low profitability. Additionally, several combined heat and power (CHP) units that are up for reinvestments, considers replacing them with either heat-only units or smaller bio-fuelled units that typically also have lower electricity output than the old coal- or gas-fired units. This reduces the available capacity of these types of controllable power plants in the Nordic region.

The most obvious challenge when replacing controllable power production with weather-dependent production is the large variations in wind power, solar power and run-of-river hydropower. Without nuclear power, the power balance in southern Sweden and in the Nordic area will become more negative than today during periods of low, intermittent production and high consumption. In these periods, the Nordic countries will depend on imports in order to cover consumption. At the same time, there will be several hours where intermittent production alone exceeds consumption.

In general, reduced nuclear and other types of thermal production capacity will increase the need for grid capacity. The impact on grid development is however strongly linked to production types, volume and where production is located. The fact that it seems like much of the traditional production will be replaced by renewables located elsewhere, adds to the need for grid development. The longer the distance between production units and consumption, the more grid investments are needed.

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3.3 Strong growth of RES – mainly by wind power

Today, there is approximately 40 TWh of wind power in the Nordic region. This will increase considerably towards 2040. The volume of weather-dependent production in general will be much larger than today, which will result in greater fluctuations in the power balance and, consequently, more volatility in the power prices. This effect tends to increase the price difference between price zones and countries, thus increasing the benefit of new grid capacity.

A considerable share of new wind projects seem to be located to the north of the Nordic region despite that local power prices are typically lower there. Two reasons for this are better wind conditions and that it is relatively easier to obtain permits in less populated areas. As the biggest consumption centres are in the southern areas, this reinforces the north–south power flow from the surplus areas in the north to the deficit areas in the south. Additionally, the power flows are also being reinforced by reduced nuclear power and increased consumption in the south. The flow pattern on interconnectors will also be influenced by the fact that, during periods of low wind production, there will be increased import from the continent or other areas.

Simulations show that grid losses in the transmission grid will increase from almost 10 TWh today, to 17 TWh in the 2040 scenario. This means that grid losses are a significant part of the total power flows. The main reason for increasing grid losses is the increased north–south power flows.

3.4 Reinvestments and existing grid capacity

The age and need for reinvestments within the existing grid are important factors for the overall level of future grid investments in the Nordic region. This is central for some of the corridors analysed in this plan, such as Norway–Denmark, Finland–Sweden and Sweden–Denmark. Reinvesting by replacing old lines and substations with new ones, often with higher capacity, has already started in the Nordic countries. The need for reinvestment will prevail over long-term.

The capacity within the existing grid is an obvious factor regarding the need and benefit of investing in expanding capacity. The same applies for the utilisation of existing capacity through improved market design and system operation. Everything else being equal, the ongoing grid development and planned improvements within market and system operation will reduce the need for new capacity investments.

Figure 1 Development of Wind Power in the Nordics

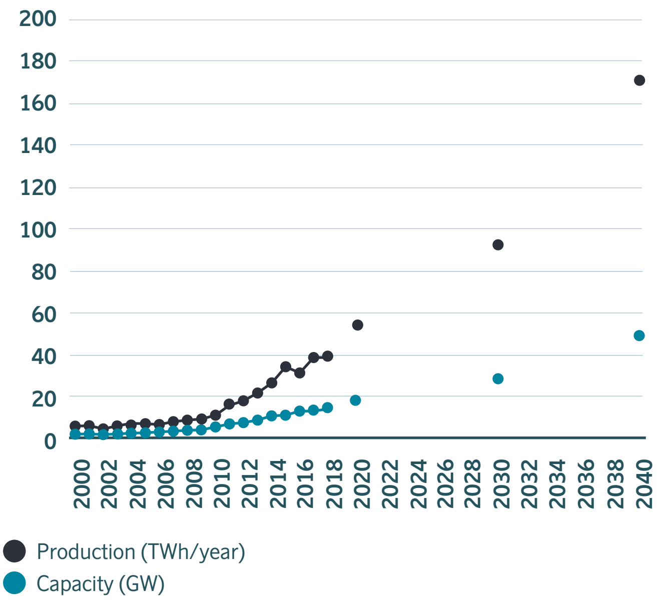

Figure 1 Development of wind power in the Nordic scenario from today to 2040. Both in annual energy production (TWh) and capacity (GW).

3.5 Higher capacity between the Nordics and the continent

Several interconnectors are being built or planned between the Nordics, continental Europe and the United Kingdom. These will increase the possibility to export power from renewable Nordic sources, but also strengthen the security of supply situation by increasing the ability to import power during periods of scarcity.

Finally, grid development is also affected by international markets and European governance. International fuel prices and the European CO_2 price affect power prices, which greatly affect the profitability of a new project.

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Based on the regional drivers for grid development, the Nordic TSOs have initiated several new projects. The most important ones from a Nordic perspective are presented below. Further details are given in the national grid development plans.

4.1 Nordic investments

The regional drivers for grid development have led to a very substantial increase in the grid investments carried out by the Nordic TSOs. Investment levels are historically high and are expected to continue to be so in the coming years. In total, the Nordic TSOs plan to invest EUR 15 billion until 2028.

The differences in the investment volumes between the TSOs are due to the different types of investments. Energinet and Statnett are, among other things, building HVDC connections to the UK in the given period, which contribute to the higher cost volume. Fingrid has quite low investment costs compared to the rest of the TSOs. This is due to Fingrid mainly building overhead AC lines, which are much cheaper to implement than underground cables and DC connections. Further, there are no offshore HVDC projects in Fingrid's investment plan for the next 10 years.

4.2 Previous Nordic reinforcements

In the last ten years, the Nordic TSOs have, through joint planning, increased the internal Nordic transmission capacity substantially by taking into operation a number of new Nordic internal reinforcements. Among them are Nea–Järpströmmen (2009), Great Belt (2010), Fenno–Skan 2 (2011), Skagerrak 4 (2014), Estlink 2 (2014) and NordBalt (2016). These have been reported on in more detail in previous Nordic grid plans.

Figure 2 Total Investments by the Nordic TSOs

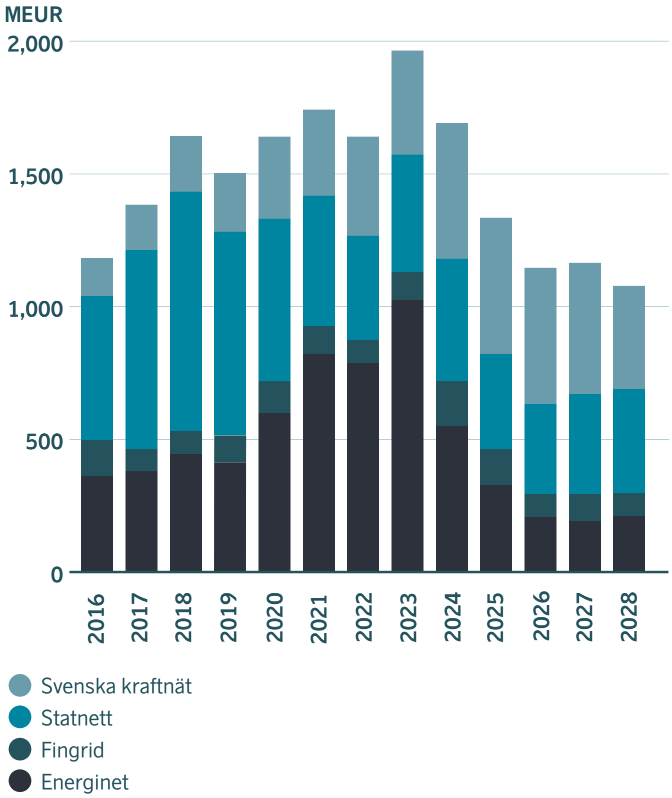

Figure 2 Overview of the investment costs in the period 2016 to 2028.

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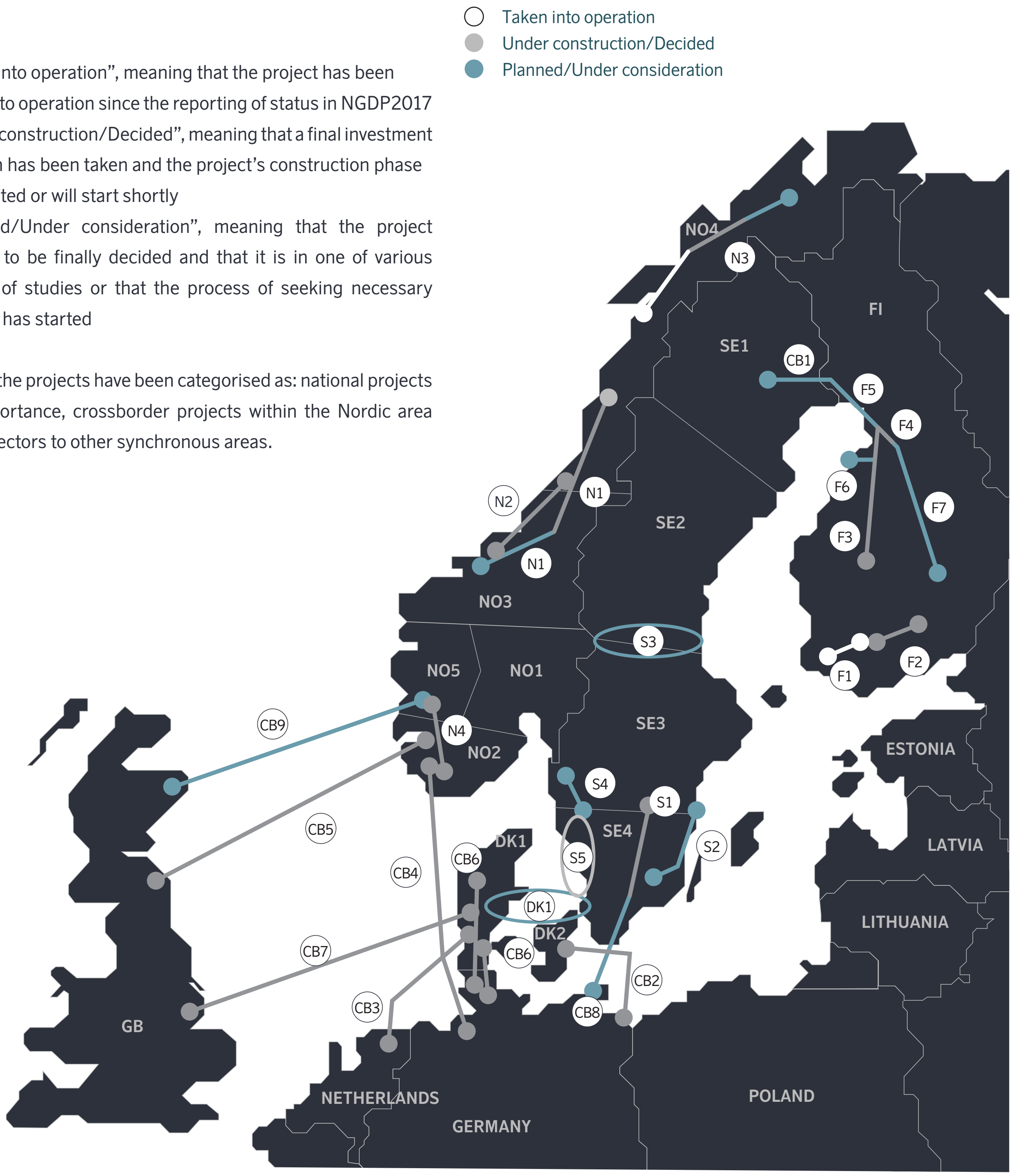
4.3 Status of projects in the Nordic area

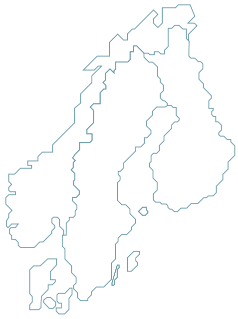
The status of different projects in the Nordic area is reported in this section as:

- "Taken into operation", meaning that the project has been taken into operation since the reporting of status in NGDP2017
- "Under construction/Decided", meaning that a final investment decision has been taken and the project's construction phase has started or will start shortly
- "Planned/Under consideration", meaning that the project has yet to be finally decided and that it is in one of various phases of studies or that the process of seeking necessary permits has started

In this report, the projects have been categorised as: national projects of Nordic importance, crossborder projects within the Nordic area and interconnectors to other synchronous areas.

Figure 3 Map of Projects in the Nordics





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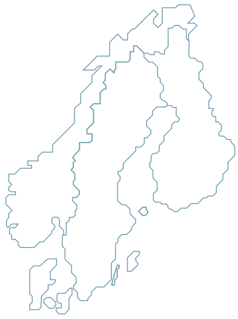
Some of the projects have a reference to PCI status. This is a status given by the European Commission to projects that have been deemed to be a Project of Common Interest to the European Union. The current label is valid for 2018–2019 and a new application procedure for the period of 2020–2021 has just started. A reference is also given to whether a current PCI project has reapplied or not.

4.3.1 National projects of Nordic importance

Each Nordic TSO has a large number of internal grid investments, including reinvestments. Some of these investments have a more direct impact on the Nordic and European system as they are needed in order to use the cross-border interconnectors efficiently. The most important internal investments from a Nordic perspective are listed below.



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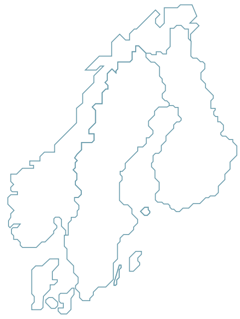
Finland

Grid development in Finland is characterised by several projects in the north–south direction and upgrade projects in Southern Finland around the main consumption areas. The north–south reinforcements will facilitate new renewables and allow further integration with Sweden, securing coverage of national demand while the projects in Southern Finland are important for local security of supply and internal capacity availability for full utilisation of HVDC connections.

	PROJECT	STATUS	DESCRIPTION
F1	**Lieto-Forssa**	Taken in to operation 2019	New 400 kV AC single circuit OHL of 67 km between substations Lieto and Forssa.
F2	**Hikiä-Orimattila**	Under construction Expected in operation 2019	New 400 kV AC single circuit OHL of 70 km between substations Hikiä and Orimattila.
F3	**North-South reinforcements P1 stage 2**	Under construction Expected in operation 2022	New 400 kV AC single circuit OHL of 300 km between Pyhänselkä and Petäjävesi. The line will be series-compensated. Built to increase the north-south transmission capacity thus enabling the integration of new renewable, new connection to Sweden and conventional generation and RES in northern Finland and to compensate dismantling of obsolescent, existing 220 kV lines.
F4	**Pyhänselkä–Nuojua**	Under construction Expected in operation 2022	New 400 kV AC single circuit OHL of 45 km between Pyhänselkä and Nuojua. OHL is first part of north–south reinforcements P1 stage 3. Built ahead to compensate dismantling of obsolescent, existing 220 kV lines.
F5	**Keminmaa–Pyhänselkä**	Planned/Under consideration Seeking permission Expected in operation 2024	This transmission line is part of the third 400 kV AC connection between Finland and Sweden (RAC3). RAC3 project has PCI status. These projects will deliver an 800 MW increase in transmission capacity.
F6	**Fennovoima NPP connection**	Planned/Under consideration Seeking permission Expected in operation 2028	This project involves a new double circuit 400 kV OHL line between Valkeus (FI) and Lumimetsä (FI). The new line is required for connecting Fennovoima’s new nuclear power plant planned to be built in Pyhäjoki. The power plant has a planned generation capacity of 1200 MW. The decision to build the connection and schedule depends on when the construction permit is given to build the Hanhikivi Nuclear Power Plant (NPP).
F7	**North-South reinforcements P1 stage 3**	Planned/Under consideration Expected in operation 2028	New 400 kV AC single circuit OHL of 300 km between Nuojua and Huutokoski. The line will be series-compensated. In Finland, renewable energy is replacing conventional fossil fuel-based generation. A significant share of renewables is located in northern Finland. Therefore, the north–south transmission capacity needs to be increased.



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Norway

Grid development in Norway is characterised by several projects in the north–south direction, which will facilitate new renewables, facilitate increased interaction with other countries, prepare increased consumption and secure an adequate security of supply.

	PROJECT	STATUS	DESCRIPTION
N1	**Voltage upgrades through Northern and Central Norway**	Several projects Under construction In operation	Will increase the capacity in the north–south direction. Detailed information given in Statnett's Grid Development Plan 2017
N2	**Fosen**	Under construction Expected in operation 2019	New 420 kV-lines in Central Norway (Fosen) in order to facilitate new wind production. Detailed information given in Statnett's Grid Development Plan 2017
N3	**Ofoten–Balsfjord–Skillemoen–Skaidi**	Under construction First part (Ofoten–Balsfjord) taken into operation in 2016/17 Second part (Balsfjord–Skillemoen) expected to be commissioned in 2021 (Skillemoen-Skaidi not final decided)	New 420 kV line (approx. 450 km) will increase the capacity in the north of Norway, mainly to serve increased petroleum-related consumption, as well as increase the security of supply. In addition, the project will prepare for some new wind power production. A line further east (Skaidi–Varangerbotn) is under consideration, however, no investments decision has been taken.
N4	**Western corridor**	Under construction Final step expected in operation 2021	Voltage upgrades in the south-western part of Norway. The project will increase the north–south capacity as well as facilitate high utilisation of the planned interconnectors. Detailed information given in Statnett's Grid Development Plan 2017

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Sweden

Grid development in Sweden is characterised by several large projects to increase grid capacity as well as studies on requests for connection of renewable power production, new industrial loads and organic load growth.

During the past few years, increasing efforts have been made to enable further load growth of city areas, since the often long permission process conflicts with city growth and the needs of new businesses.

	PROJECT	STATUS	DESCRIPTION
S1	**SouthWest Link** 2*600 MW	Under construction Currently (June 2019) in Trial Run. Expected in operation November 2019	Will increase the internal Nordic capacity in a north–south direction between areas SE3 and SE4. This will make it possible to handle an increased amount of renewable production in the north part of the Nordic area as well as an increase in trade on NordBalt and the planned Hansa PowerBridge with less risk of limitations. The project has been delayed due to difficulties in the implementation phase.
S2	**Ekhyddan – Nybro - Hemsjö**	Under consideration Expected in operation 2024	This is currently a PCI project and has reapplied for continued status. New 400 kV AC single circuit OHL of 70 km between Ekhyddan and Nybro and a new 400 kV AC single circuit OHL of 85 km between Nybro and Hemsjö. The reinforcements are necessary to fully and securely utilise the NordBalt interconnection that is connected in Nybro. The project has been delayed due to longer than expected time to receive permission.
S3	**North-South** SE2 – SE3	Planned/Under consideration Expected in operation between 2019 and 2040+	A set of almost 50 different projects which will increase the capacity between price areas SE2 and SE3. In the near term, new shunt compensation, upgrades of existing series compensation and station components are planned for installation between 2021 and 2025. Three of the oldest of the 400 kV lines and the three 220 kV lines are expected to be replaced with new 400 kV lines with a higher transfer capacity. The first replacement is planned for 2027–2030. These reinforcements will together significantly increase the north–south capacity in the internal Nordic transmission grid, from current 7,300 MW to more than 10,000 MW.

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Sweden

	PROJECT	STATUS	DESCRIPTION
S4	**Skogssäter - Stenkullen** Swedish west coast	Planned/Under consideration Seeking permission Expected in operation 2023	New 400 kV single circuit overhead line that will increase capacity on the Swedish west coast. This will lead to better trading capacity between Sweden, Denmark and Norway. The project has been delayed due to longer than expected time to receive permission.
S5	**Sweden southwest**	Planned/Under construction Expected in operation between 2021 and 2028	Replacement and thermal upgrade of several old 400 kV overhead lines on the western coast of Sweden, along a line from Trollhättan (SE3) to Malmö (SE4). This corridor is highly important for the exchange of power between Norway–Sweden–Denmark. The upgrade programme is required to maintain high availability and internal capacity of the Swedish west coast corridor. A high operational security on these power lines is crucial for trading capacities SE3–NO1, SE3–SE4, SE4–DK2 and SE4–DE. For more details, refer to the Swedish System development plan 2018–2027.

Denmark

Grid development in Denmark includes projects for connection of new consumption (data centres), new generation (offshore wind farms) and domestic reinforcements due to connection of new interconnectors. Some of the most important investments are summarised in the table below.

	PROJECT	STATUS	DESCRIPTION
DK1	**Endrup-Idomlund**	Decided Expected in operation 2023	All projects are 400 kV domestic transmission lines. The purpose of the investments is to integrate ongoing and planned connections of renewable generation (offshore wind farms) and to connect new interconnectors (COBRA, Viking Link, DK West-Germany etc., see section 4.3.3) to the domestic grid.
	Revsing-Landerupgaard	Under consideration Expected in operation 2024	
	Bjæverskov-Hovegaard	Under consideration Expected in operation 2023	

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4.3.2 Cross border projects within the Nordic area

	PROJECT	STATUS	DESCRIPTION
CB1	**3rd AC** Sweden – Finland	Planned/Under consideration Seeking permission Expected in operation 2025	This is currently a PCI project and has reapplied for continued status. New 400 kV AC line cross the northern border between Sweden and Finland. The line will increase trading capacity and the possibility to exchange system services as well as increase the power adequacy in Finland. The project F5 (Keminmaa–Pyhänselkä) in the Finnish project list is a part of this cross-border connection, and has also PCI status.

4.3.3 Interconnectors to continental Europe/the UK

	PROJECT	STATUS	DESCRIPTION
CB2	**Kriegers Flak CGS** 400 MW Denmark East – Germany	Under construction Expected in operation 2019	Secure connections to shore are vital for the Kriegers Flak offshore wind farm. An offshore interconnector is being developed in collaboration with the German TSO (50Hertz Transmission GmbH). The new interconnector will take advantage of the proximity of Danish and German wind farms by adding short cables and thus connecting the wind farms to both Germany and Denmark. This is currently a PCI project, but has not reapplied for continued status.
CB3	**COBRA** 700 MW Denmark West – Netherlands	Under construction Expected in operation 2019	The project from Endrup in Denmark West to Eemshaven in Holland is under construction with the installation of cabling and construction of converter stations in 2017 and 2018 with the aim of going into operation in Q3 2019.
CB4	**NordLink** 1,400 MW Norway – Germany	Under construction Expected start energy exchange end 2020; Expected market operation Q1 2021.	HVDC subsea interconnector between southern Norway (Tonstad) and northern Germany (Wilster). The interconnector will improve security of supply both in Norway in dry years and in Germany and continental Europe in periods with negative power balance (low wind, high demand etc.). Additionally, the interconnector will be positive both for the European market integration, for facilitating renewable energy and also for preparing for a power system with lower CO_2 emissions.

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	PROJECT	STATUS	DESCRIPTION
CB5	**NSL Link** 1,400 MW Norway – the UK	Under construction Expected market operation end 2021.	720 km long HVDC subsea interconnector between western Norway (Kvilldal) and eastern England (Blyth). The interconnector will improve security of supply both in Norway in dry years and in the UK in periods with negative power balance (low wind, high demand etc.). Additionally, the interconnector will be positive both for the European market integration, for facilitating renewable energy and also for preparing for a power system with lower CO_2 emissions.
CB6	Denmark West – Germany	Under construction Expected in operation in 2020 Decided Expected in operation in 2023	On the Denmark West and Germany border there are two projects. The east coast project (step 3) is a new 400 kV line from Kassoe (DK) to Audorf (DE), increasing the capacity on the border to 2,500 MW in 2020. For this project Energinet has obtained the planning permission and the project is now in the construction phase. The west coast project is a project of a double 400 kV line from Endrup to Klixbüll where it is to connect with the two 400 kV lines being build up along the German western coastline in Schleswig Holstein. This project increases the possibility of exporting and importing electricity on the border from 2,500 MW to 3,500 MW in 2023. Both projects have currently PCI status. Only the west coast project has reapplied for continued status.
CB7	**Viking Link** 1,400 MW Denmark West – the UK	Decided Expected in operation 2023	The Viking Link project was approved by the Ministry on 30 October 2017. The project aims at integrating the electricity markets of the UK and DK to increase the value of wind power as well as improving security of supply in the UK in the long term. The project is closely connected to an expansion of the internal western Danish grid as well as additional interconnection to Germany, in the so called West Coast project. This is currently a PCI project and has reapplied for continued status.
CB8	**Hansa PowerBridge** 700 MW Sweden – Germany	Planned/Under consideration Seeking permission Expected in operation 2025/26	A HVDC subsea interconnector between Hurva in southern Sweden and Güstrow in northern Germany. A decision to start further project work on permissions was taken in early 2017.
CB9	**NorthConnect** 1,400 MW Norway – Scotland	Under consideration	A 650 km long subsea interconnector between western Norway (Sima) and eastern Scotland (Peterhead).

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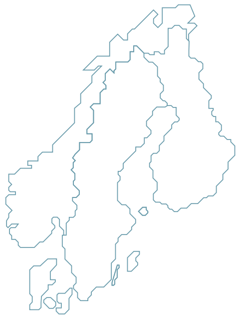
For this NGDP2019, five bilateral studies have been done based on the five corridors of interest identified in NGDP2017. The studies were based on a common Nordic scenario and evaluation framework, which are presented in this chapter.

5.1 Nordic reference scenario

A common Nordic scenario was built during 2017/2018. Firstly, it strengthens Nordic cooperation as the Nordic TSOs can agree on a joint view of the development of the Nordic region. Secondly, the bilateral studies require a common view of future development. Although the Nordic TSOs use different modelling, and sometimes different tools, a common set of input data is needed.

The scenario consists of demand, generation per technology and transmission capacities between price areas. It is based on each TSO's national view but discussed and aligned on a Nordic level. For the rest of Europe, the scenario is based on ENTSO-E's scenario Sustainable Transition. In addition, each TSO has its own datasets that describe detailed technical data.



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5.1.1 Main assumptions

Demand is assumed to increase from 403 TWh in 2020 to 461 TWh in 2040, i.e. by approximately 15 per cent. The sectors providing the increase are transportation, data centres and new industry, as presented in chapter 3. The development of demand is highly uncertain, and there is a need for sensitivity analyses.

Increase in renewable generation is primarily described by a growth in wind power, and to some extent in solar power. Some small hydropower projects are being built in Norway, while bio-fuelled generation is expected to remain fairly stable.

Wind power projects are currently primarily being located in the north of the Nordic region despite that area prices are generally lower there. That new generation is being located far from the main demand is somewhat of a challenge for the grid development.

Figure 4 Demand

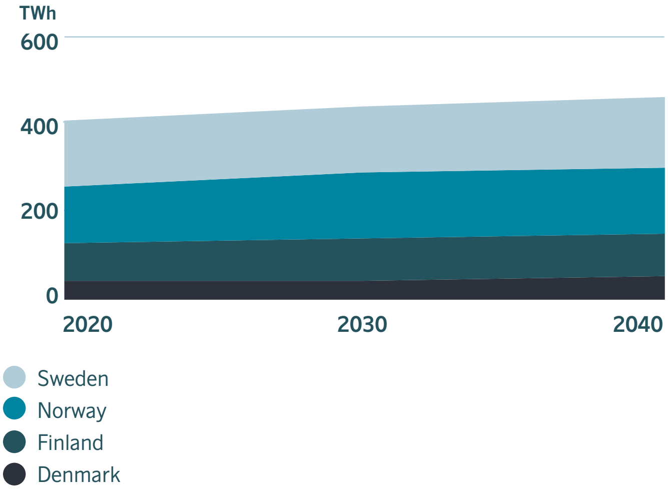


Figure 4 Development of demand in the Nordic countries.

Figure 5 Wind Power

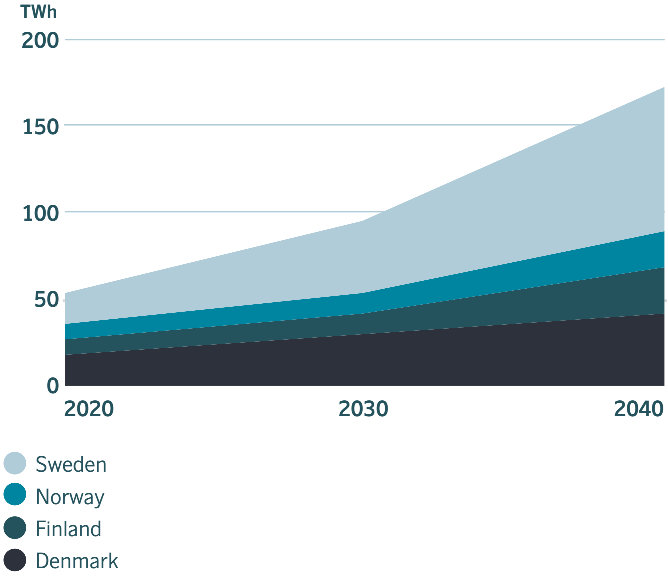
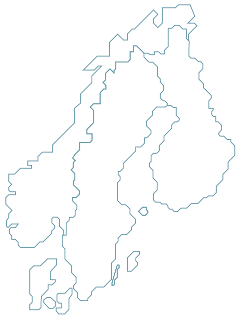


Figure 5 Development of wind power in the Nordic countries.



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Two new nuclear units are being built or planned in Finland, while two units are being decommissioned in Sweden. During the 2040s, the nuclear plants in operation will reach the end of their estimated technical life span. Apart from the Hanhikivi unit in Finland, no further units are being planned.

In the scenario, Swedish nuclear power is assumed to be decommissioned by 2040 although a technical lifetime of 60 years indicates operation a few years after 2040. The assumption is based on the political agreement of a 100 per cent renewable Swedish power system by 2040, and the idea that the 2040 dataset should also reflect the long-term future of the power system.

Fossil-fuelled thermal units, both condensing power plants and CHP, are meeting difficult commercial conditions and several units have been, or might be, decommissioned or possibly replaced with heat-only units, thus weakening the power balance.

The net transfer capacities (NTCs) between price areas are based on projects that have been either communicated in the ten-year network development plans or identified as key potential future investments.

The scenario assumes an increase in demand flexibility and storage. However, both volume and prices are surrounded by a large uncertainty. It is assumed to partly be based on technology not yet fully available, like batteries. Furthermore, since demand flexibility is not required much today, it is not yet clear how much flexibility is available currently and how much will have to be provided by new products or technologies like batteries or power-to-gas (P2G).

Consistency and rational behaviour of market participants are major assumptions in the scenario. This means that the results agree with the inputs; e.g. that assumed installed generation capacity must show profitability at the resulting price level. Different consistency checks have been made throughout the process of developing the scenario, making sure that assumed generation and demand flexibility fit the scenario design.

Figure 6 Nuclear

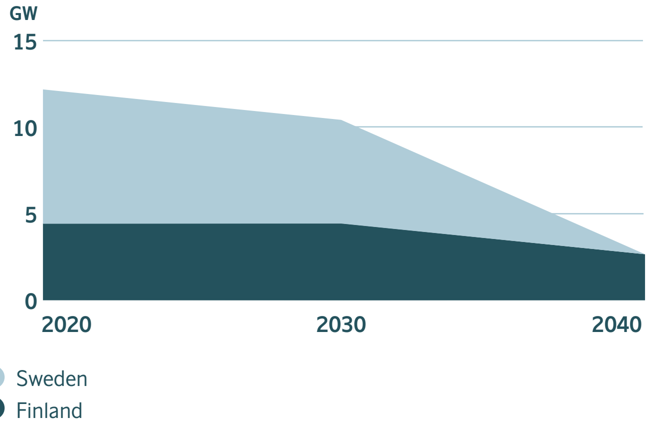

Figure 6 Development of nuclear power in Finland and Sweden.

Figure 7 Fossil-fuelled Thermal Power

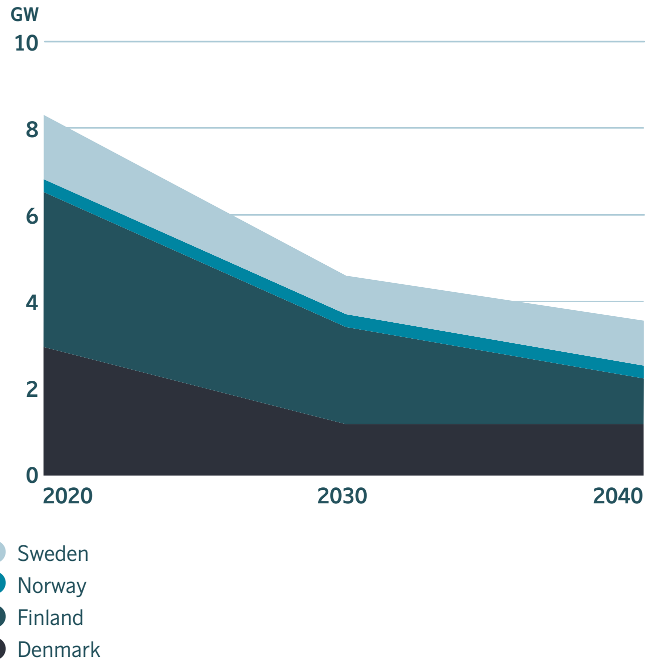

Figure 7 Development of fossil-fuelled thermal power in the Nordic countries.

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5.1.2 Overview of results

The Nordic reference scenario was modelled in the market simulation models for each TSO. The aim was not to have identical modelling, but to harmonise modelling so that main results are reasonably similar. Mainly the harmonisation was done by comparing area electricity balances and prices (Figure 8).

Generally, the tuning of the models was successful, and results were rather similar. With the common scenario being modelled separately by each TSO, the combined result gains robustness.

Concerning the energy balances for Nordic countries, it can be noted that

- Denmark is gradually turning from being a net importer to a net exporter, due to a strong increase in both wind and solar capacity. Also, the power demand in Denmark will increase notably, mainly due to electric vehicles, heat pumps and data centres, but that increase will be covered by the new generation.
- Finland will remain a net importer of electricity, although the energy import will decrease from today's level due to new nuclear reactors and increase in wind power capacity. However, in various situations there may be an increasing need for power import.
- Norway will remain a net exporter of electricity. There will be some increase in hydro production, but the higher power generation will be mainly due to an increase in wind capacity.
- Sweden will also remain a net exporter of electricity, even though all nuclear reactors are closed in the 2040 scenario. The nuclear capacity will be replaced with large amounts of new wind power, and also some solar installations. The electricity demand is expected to increase from 2030 to 2040 due to new process solutions in the steel industry, where so-called HYBRIT technology is gradually replacing traditional coalbased steel mills.

Figure 8 Average Power Price 2030

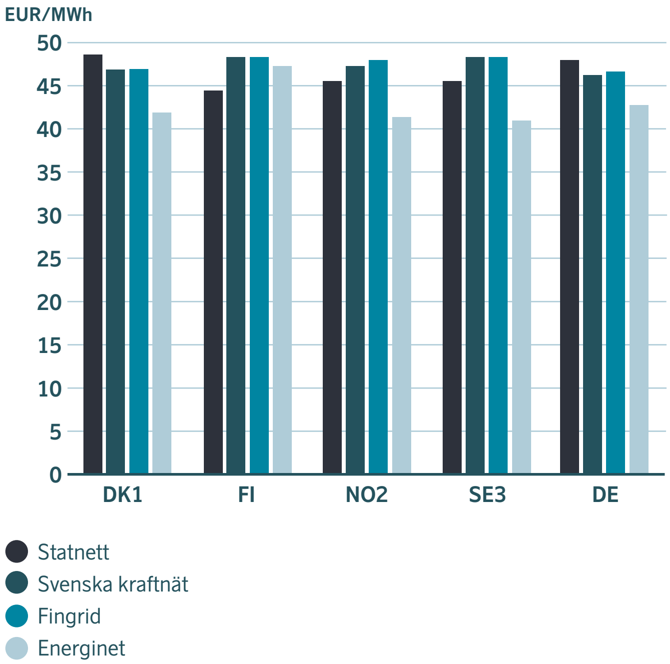
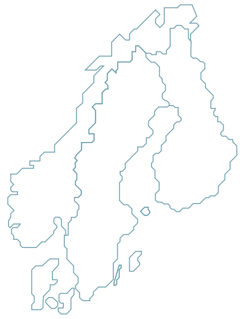


Figure 8 Example of result comparison between TSOs.



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The Nordics will have a positive energy balance i.e. annual total demand is less than the annual total generation of electricity for all analysed years (Figure 9). Because of that, the Nordics will remain a net exporter of electricity.

However, as the generation will be more variable and weather dependent, the challenges of maintaining instantaneous power balance will increase. That can be seen especially in 2040 situation, where the expected peak demand is higher than the sum of schedulable generation and assumed demand flexibility (Figure 10). When the expected available generation from wind and solar power is taken into account, the resulting peak residual demand is somewhat lower.

Figure 9 Nordic Energy Balance

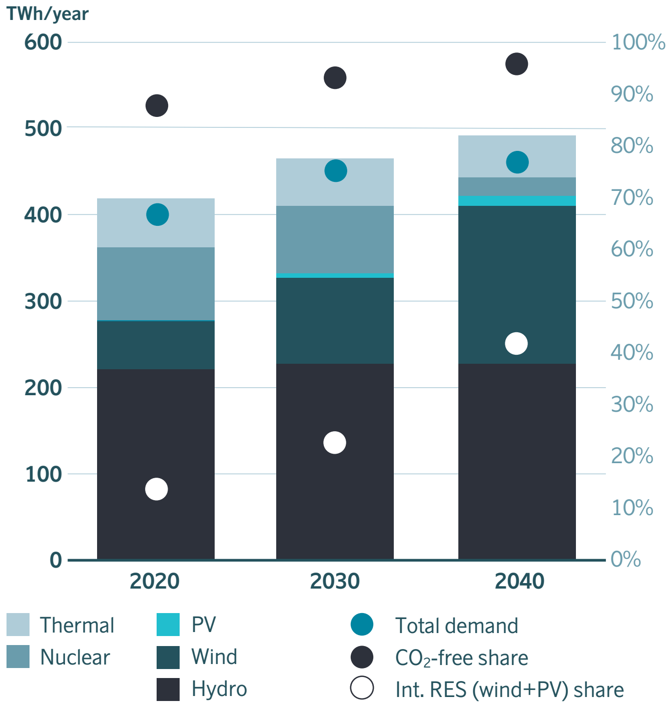


Figure 9 Nordic energy balance [TWh/year].

Figure 10 Nordic Schedulable Generation and Flex

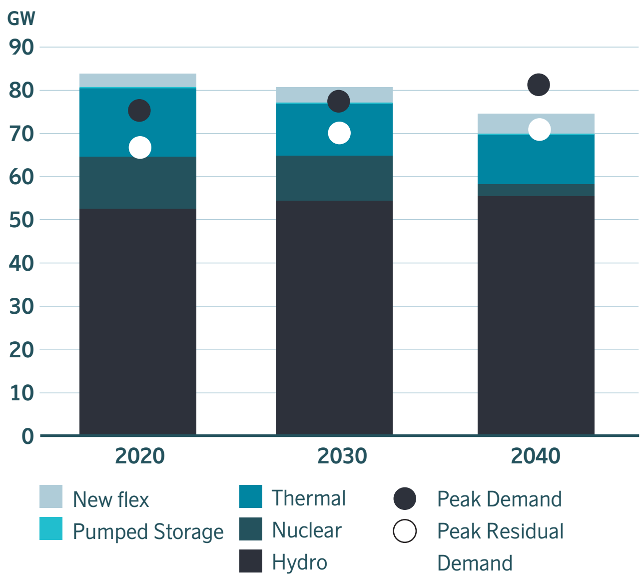
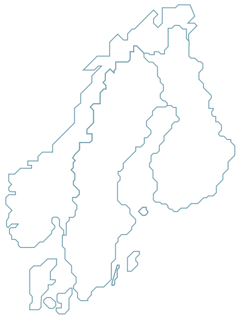


Figure 10 Nordic power balance [GW].



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The annual average power prices for Nordic areas are in the range of 40–50 EUR/MWh for both 2030 and 2040, and the Nordic price level is generally closely linked to the continental European prices (Figure 11). With a higher share of wind and solar power combined with lower nuclear and thermal capacities, the price volatility increases substantially from 2030 to 2040. By 2040, up to 20 per cent of all hours will have close-to-zero prices and, on the other hand, the number of hours with extremely high price will also increase. Similar behaviour is seen in both Nordic and continental European price areas (Figure 12).

In addition to higher volatility, the development is also towards higher area price differences. The nuclear power that will be closed is located in southern Sweden while a large part of the replacement wind power is located in northern areas of Sweden, Finland and Norway, thus increasing the need for power transmission from north to south. Despite the ambitious plans to increase the north–south transmission capacity in Sweden, the connections remain congested at times.

Figure 11 Average Power Prices for 2030 and 2040

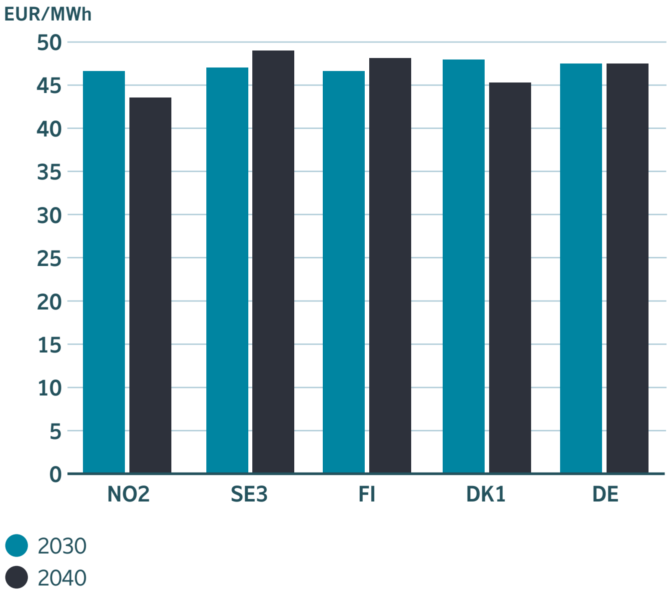

Figure 11 Annual average electricity prices [EUR/MWh] for various modelled areas.

Figure 12 SE3 and DE Price Duration Curves for 2030 and 2040

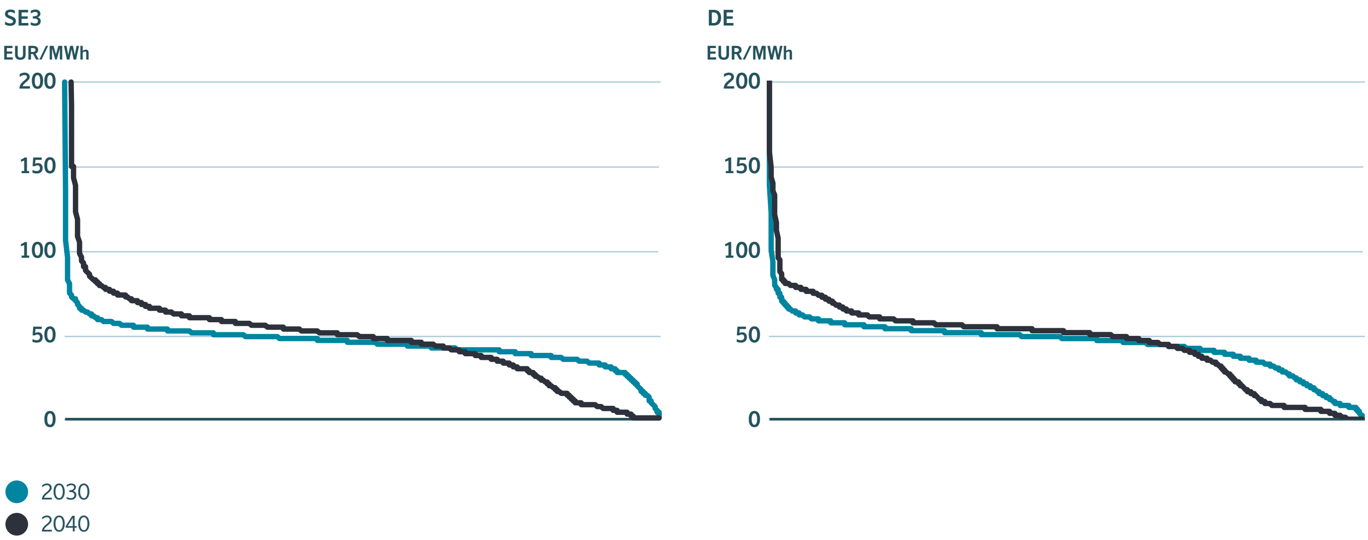

Figure 12 Annual price [EUR/MWh] distribution for Sweden and Germany.

5 Planning for the future

5.1.3 Uncertainties surrounding future development

The Nordic reference scenario process focused on the development of the base scenario. There are no definitions for specific common sensitivities for the bilateral studies, but within the scenario process, several uncertainties were identified and discussed:

- Fuel and CO_2 prices
- Consumption growth
- Increased scarcity towards 2040, how the flexibility will be provided and at what cost
- Sweden without nuclear power or with some nuclear power
- Role of batteries and other types of storage in the Nordics
- Reduced availability of the grid i.e. transmission capacity in some other connections set to lower level
- Capacity between the Nordics and Germany or development of grid capacity in Germany

Then again, when the Nordic reference scenario is utilised in the bilateral studies, a set of relevant sensitivities is included in all studies. Mainly these sensitivities focus on:

- Volumes of wind and solar power
- Phaseout of Swedish nuclear power
- Development of electricity demand
- Development of demand flexibility
- Capacities in other studied transmission corridors

5.2 Common evaluation framework

A Cost Benefit Analysis (CBA) is a systematic approach to estimate the strengths and weaknesses of alternatives and thereby determine if an investment or decision is sound. The four TSOs have worked together to ensure a harmonised CBA framework for evaluation of Nordic cross-border investments (see Annex), in order to make the results transparent and comparable between studies.

In principle, the common CBA means taking into account all relevant costs and benefits, from a Nordic socioeconomic standpoint. However, the levels of detail in the assessments depend on the given stage of the actual project under investigation. As most of the bilateral studies are in an early stage, the focus is on market benefits and investment costs. An overview of which CBA factors each study has used is given in Table 1.

All the bilateral studies have, as a minimum, looked into market benefits and investment costs. Only the Sweden–Finland study is far enough along in the process to look into most of the CBA factors. Although, some of the factors have only been partly included, which is indicated with parentheses in Table 1, i.e. the value of security of supply has been estimated but is not included in the market benefits. Also, integration of renewable electricity has been looked into, but there are no specific projects linked to the study.

The scope of the analysis is for the Nordic countries. The analysis is based on the Nordic reference scenario, which is commonly accepted by the Nordic TSOs. The reference alternative used in the studies is the situation where the existing grid is continued without new major investments. Major investments that are planned or decided, but do not yet exist are included in the reference alternative. In case the studied interconnection will replace an old one, the old one is first taken out.

The net present value (NPV) method is used with a 4 per cent real discount rate per year and the analysis period is 40 years based on a “normal” expected technical lifetime (25 years is used as an sensitivity analysis). The results are reported as the difference between the alternative and the reference alternative.

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Table 1
Table of CBA Factors Used in the Studies

NAME OF STUDY		DK-NO	DK-SE	SE-NO	SE-FI	NO-FI
Monetised effects						
Investment costs	MEUR	X	X	X	X	X
Operational costs	MEUR	X	X	X	X	
Market benefits	MEUR	X	X	X	X	X
- of which from connecting renewable energy	MEUR					
- of which improved security of supply	MEUR				(X)	
Transmission losses	MEUR	X**		X	X	X
- impact on CO_2 emissions*	$ktCO_2$/ year					
Non-monetised effects						
Integration of renewable electricity	These should be reported as text				(X)	
Security of supply – system adequacy					X	
Security of supply – system stability and resilience						
Environmental and social impact					X	
Flexibility and trade balancing					X	

Table 1 Overview of which CBA factors each study has used, how each factor should be reported and which elements the common evaluation framework covers.
**Monetisation is included in market benefits.*
***Only done partly by Statnett.*

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6 Five Nordic corridors

In this chapter, we briefly describe the main results and conclusions of the five bilateral studies.

The transmission corridors of special interest are characterised by being borders that are expected to see a potentially large increase in power flows. These flows could either be from large amounts of Nordic renewable production being exported through new and existing interconnectors or imported and transported to larger consumption areas when there is low local production of renewable electricity.

Figure 13 Illustrations of the Corridors of Interest

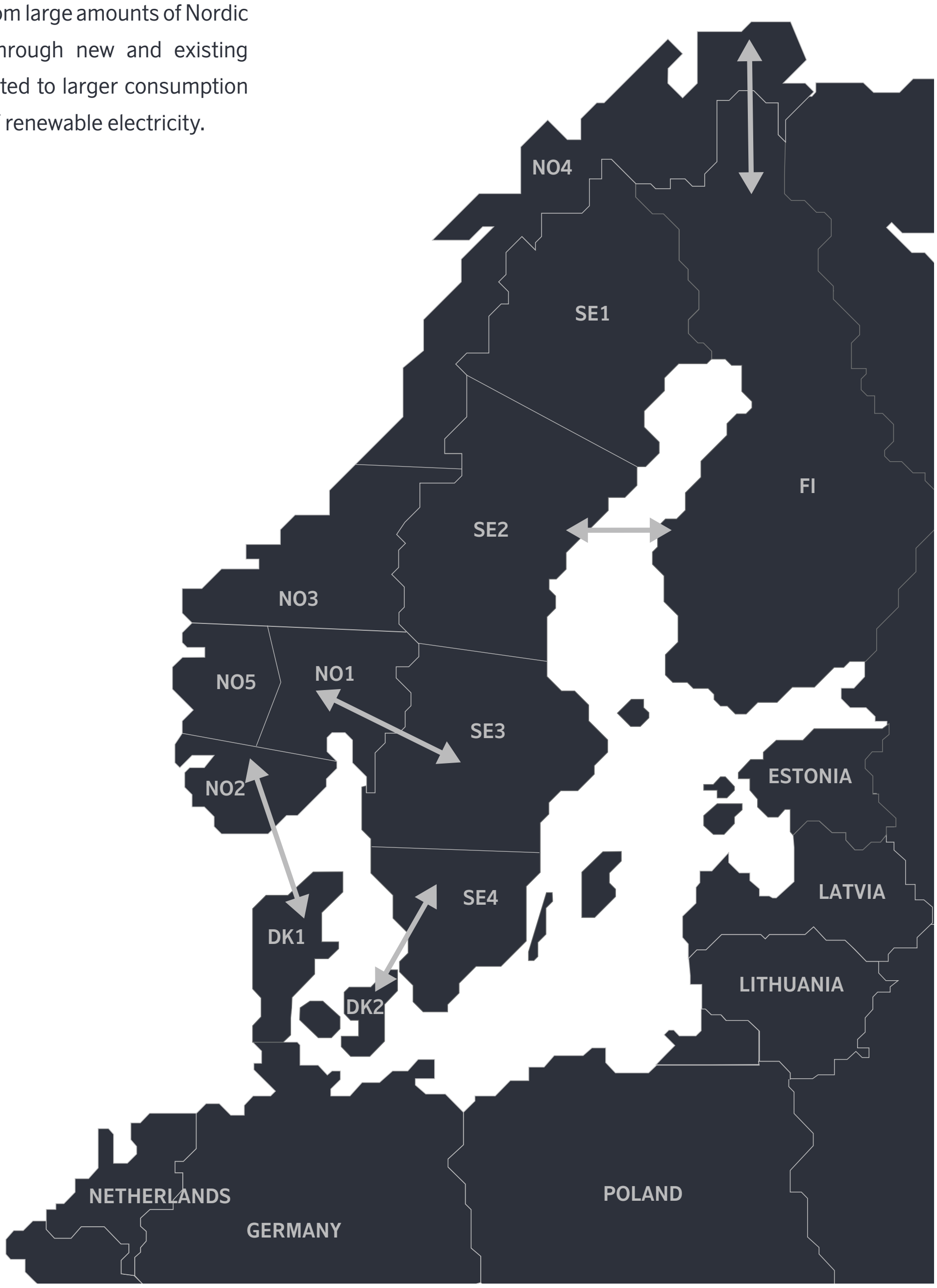

Figure 13 Illustration of the corridors of interest.

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Five Nordic corridors

6.1 Norway–Denmark

6.1.1 Background and drivers

Today, the net transfer capacity between Norway and Denmark is 1,700 MW, distributed on four interconnectors, Skagerrak 1, 2, 3 and 4. The first two, with a capacity of 500 MW in total, may reach the end of their expected technical lifetime within the next decade[3]. From Norwegian side, the concession to construct Skagerrak 4 was also based on the need to increase the security of supply, because Skagerrak 1 and 2 were getting old and close to their technical lifetime.

This bilateral study analyses the potential value of additional interconnector capacity, from a baseline where Skagerrak 1 and 2 are no longer in operation. This value of additional capacity could originate from keeping Skagerrak 1 and 2 in operation through repairs and maintenance. However, the value also gives an indication of reinvesting in Skagerrak 1 and 2, although there are several uncertainties and sensitivities as listed in chapter 6.1.3.

6.1.2 Outline of the study

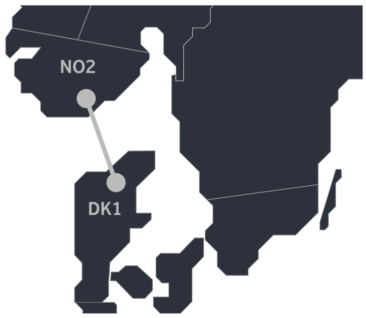
The aim is to conduct an early evaluation of the economic potential

This study is an assessment of the benefits and costs of reinvesting in parts of the transmission capacity between Norway and Denmark. This includes identifying and describing main drivers and uncertainties related to market benefits. In addition to the Nordic reference scenario, central uncertainties regarding the development of the Nordic and European power market are analysed. The potential value shown is based on a well-functioning market operation for new capacity. We underline that the study is an early stage analysis and non-binding.

Description of the base case

This study analyses the market benefit of adding 700 MW. In 2030, this means calculating the benefit of increasing the capacity from 1,200 to 1,900 MW, as Skagerrak 1 and 2 are assumed to be out of operation by then. In 2040, it is assumed that Skagerrak 3 is out of operation as well. Hence, the benefit of increasing the capacity from 700 to 1,400 MW is calculated.

Figure 14 Map of the Skagerrak Cables Between Norway and Denmark



[3]Skagerrak 1, 2 and 3 were put in operation in 1976, 1977 and 1993, respectively. Skagerrak 4 is from 2014.

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Five Nordic corridors

It is important to underline that the real lifetime is uncertain. Under normal conditions, lifetime extensions are possible. Therefore, it might be possible to operate Skagerrak 1, 2 and 3 longer than assumed. In addition, Skagerrak 4 is a monopole, which cannot operate alone without introducing electrodes or metallic return. Therefore, Skagerrak 4 is assumed to operate with an additional cable for return current as a bipolar in the 2040 base case.

6.1.3 Results and analytical conclusions

The market benefit increases towards 2040

Figure 15 shows the combined market benefits for the Nordic countries of increasing the capacity by 700 MW in 2030 and 2040. The numbers from Energinet are calculated in the BID model, while the Statnett numbers are calculated in the Samnett model. The differences in results are mostly due to a more detailed representation of the hydropower system in the Nordic area in the Samnett model. In addition, there is higher European price volatility in the Statnett simulations[4].

One driver for more benefits before 2030, is the big increase in the capacity from Denmark to the continent and the United Kingdom in the coming years. This includes 700 MW to the Netherlands (COBRA cable), 1,400 MW to the United Kingdom (Viking Link), Kriegers Flak (400 MW) between DK2 and Germany and a capacity increase between DK1 and Germany of almost 2,000 MW. In addition, the capacity given to the market between DK1 and Germany is expected to increase compared to historical levels. Consequently, the Danish prices are expected to become more linked to the continental prices and less to Norwegian prices. This will be reinforced by a decommissioning of Skagerrak 1 and 2.

Both models show that the market benefit increases over time. As a result, the benefit more than doubles from 2030 to 2040. The two main drivers for this are:

- More volatility in the Danish prices during the period from November to March, mostly due to more volatile prices in the continental market.
- More wind and to some extent solar power in Norway lowers the Norwegian power prices – especially during periods of high production and low consumption. This adds to the price difference and increases the benefit.

Figure 15 Market Benefits for 2030 and 2040

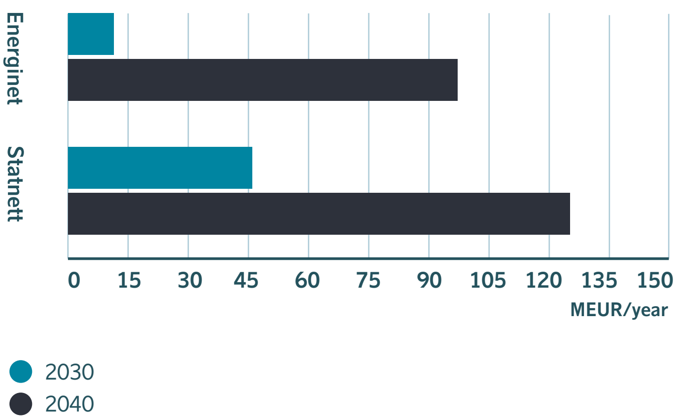
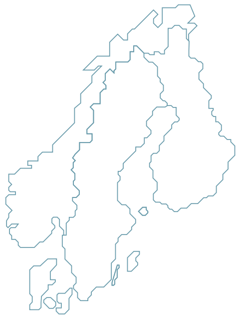


Figure 15 Total annual Nordic benefit for the base case (700 MW) + 700 MW. Grid losses are included in Statnett numbers, numbers from Energinet are without grid losses.

[4] Statnett also uses BID to model the European power market outside the Nordics.



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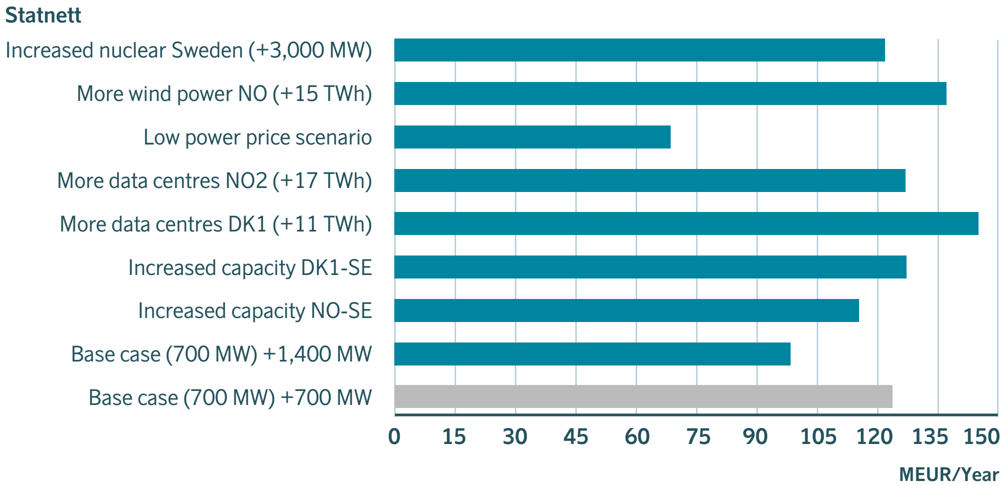
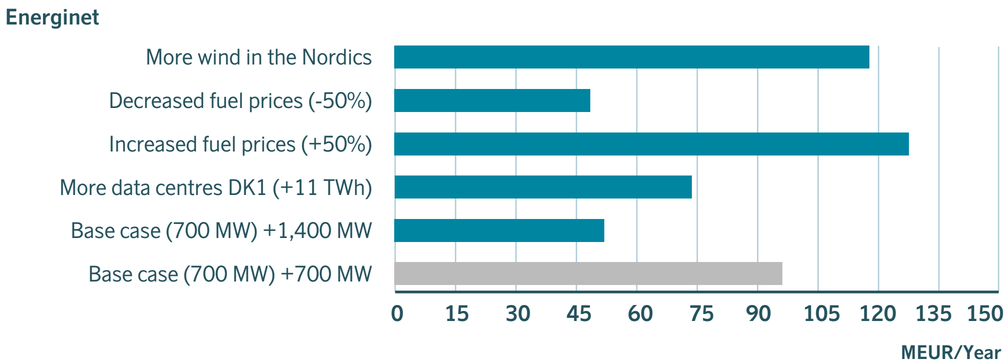
Uncertainty and sensitivities related to market benefits

We have developed a set of common sensitivities for both 2030 and 2040. The intention is to better understand how changes in one important parameter affect the results and cover relevant uncertainty. The sensitivities are developed in line with knowledge and experience from similar studies. All the sensitivities are simulated with +700 MW capacity. The results from year 2030 are almost equal to 2040, therefore we have chosen to show only sensitivities from the year 2040.

More data centres in Denmark and increasing wind power in Norway have a positive impact. Low power prices due to low gas and CO_2 prices have a negative impact, especially in 2040. However, even though the benefit decreases by almost 50 per cent, the benefit is still reasonably high. Overall, the results also show that there are few cases where the benefits are significantly reduced and indicate a small downside risk related to the benefits. We also see that the benefit for the next +700 MW capacity is nearly as high as the first +700 MW, which indicates the same. However, there are uncertainties not taken into account in this analysis.

Figure 16 Sensitivity Results for 2040





Sensitivity results in the 2040 scenario. Sensitivities are simulated with +700 MW capacity. The base case +700 MW is coloured grey. Base case (700 MW) + 1,400 MW shows the additional value of the extra 700 MW.

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Five Nordic corridors

Of importance is:
Future experience from handling of bottlenecks and the utilisation of the interconnectors in connected countries NO/DK/DE/ NE/UK

- Specific grid development progress and how future internal congestions in Germany is handled
- Developing of markets including trade of capacity and flexibility
- Future regulatory framework in NO/DK/EU/UK delivering on a well-functioning market
- General system aspects and progress of needed solutions listed in the "The way forward - Solutions for a changing Nordic power system".

Socioeconomic calculation – high net benefit in the base case
In this section, we present a simplified socioeconomic calculation of a 700 MW capacity increase. The cost estimate is based on other similar HVDC connections.

In the 2040 reference alternative, only Skagerrak 4 is included with a return cable current. The cost of the return cable is, however, not included in the net present value calculation. A cable for return current would involve some extra costs. Results from other studies show large variations in the costs, as the costs depend on the chosen technical solution, distance etc. The higher the return cable costs, the more attractive it is to reinvest in Skagerrak 1 and 2, as they would then be used as a return cable for Skagerrak 4.

Already in 2030, the benefits are on a level that makes the reinvestments profitable. The simulations indicate further increased benefits after 2040. In the Nordic reference scenario, the benefits are higher than the costs after approximately 11 years from the point of reinvestment, which is set to 2026, and operational from 2030. The simulations indicate a net present value of EUR 600–1,000 million in this scenario.

Most of the Norwegian benefit comes from increased producer and consumer surplus. The changes in congestion rent are relatively small compared to the producer and consumer surplus. Most of the Danish benefits come from increased congestion rents, and not producer and consumer surplus like in Norway. The reason is that the increased capacity between Norway and Denmark has small price effects on the Danish power prices.

Future progress
This bilateral analysis both indicates a high value of keeping todays capacity in operation and a positive cost benefit of a future reinvestment. However as described, there is a range of uncertainties not investigated yet. Thus, the possible decision to start a more detailed study will be taken when there is updated information on the uncertainties described. Hence a new update of this study will not be started at this stage.

Figure 17 Net Present Value

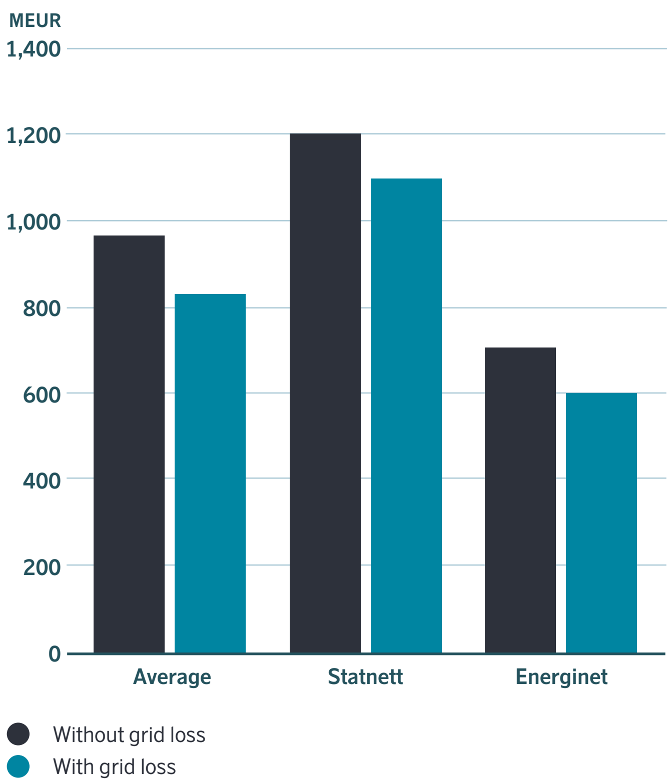


Figure 17 Net present values for the base case with increased capacity of 700 MW. The figures without grid losses only include market benefits, investment and maintenance costs. The grid losses are only estimated by Statnett. As Statnett does not simulate DK1, the internal losses in DK1 and the losses on the interconnectors going out of the Nordics from DK1 are not included.

6 Five Nordic corridors

6.2 Norway–Sweden

6.2.1 Background and drivers

A possible decommissioning of Swedish nuclear power plants and a rapid increase of wind power would be the main drivers for investigating the Norway–Sweden corridor (NO1–SE3). If the Swedish nuclear plants are decommissioned, increased transmission capacity between southern Sweden and Norway may be beneficial both to ensure generation adequacy and to integrate large volumes of wind power. However, thorough analysis of the future adequacy issues is beyond the scope of this study, and should be addressed in future studies.

6.2.2 Outline of the study

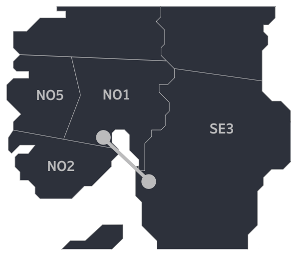
The scope of the study is to investigate the potential benefits for the Nordic power system of increasing the capacity between Norway and southern Sweden. This includes identifying and describing main drivers and uncertainties related to the market benefit. The analysis is supplemented with sensitivity cases. The sensitivity cases investigate both the impact from other studied corridors and impacts from variations of the Nordic scenario.

The study is an early assessment and the focus is on market simulations, market benefits and roughly estimated costs. However, a general technical screening of possible routes has been done in order to understand how a possible new line can be realised. Two options turn out to be feasible, the first is a DC connection from Rød in Norway to a substation north of the Gothenburg area, and the second is an AC connection from the Hasle area in Norway towards southwest Sweden.

This study has analysed the years 2030 and 2040. We have looked at both AC and DC connections. A DC connector seems to provide better capacity utilisation, and hence a higher benefit than an AC solution. All benefit values are shown with a DC solution. This is further explained later in this study.

Both the AC and DC alternative add 1,000 MW of transmission capacity in the corridor compared to today's max capacity of about 2,000 MW. This corridor has historically had frequent capacity restrictions due to internal grid issues or outages.

Figure 18 Map of a DC Connection Between Norway and Sweden



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Five Nordic corridors

6.2.3 Results and conclusions

The market benefit increases, especially from 2040

Figure 19 shows average market benefits for the Nordic countries of increasing the capacity by 1,000 MW. The figures are average values from Statnett and Svenska kraftnät. Both simulations have been done with the Samnett model, which uses the EMPS market model as well as taking physical grid constraints into account with a flow-based approach

Towards 2030, both increased wind power in the Nordic area and reduced nuclear power in Sweden are the main drivers behind the increasing market benefits. From 2040, the main drivers are the same, but the changes are a lot bigger. Wind power increases overall by almost 60 TWh in Norway and Sweden, and nuclear power is reduced by 40 TWh between 2030 and 2040. Full decommissioning of nuclear power and additional growth in wind power create higher price volatility and decreasing capacity margin in the whole Nordic power system.

Most of the benefits have been extracted with the first 1,000 MW capacity increases. A further increase of 400 MW will increase the benefits by almost 20 per cent. This indicates decreasing benefits compared to the +1,000 MW alternative.

Increased capacity between Norway and Sweden would mainly reduce the power prices in Sweden, especially during the winter period. Norwegian prices are almost not affected at all. The price differences in the 2030 scenario between south-eastern Norway and south-western Sweden are reduced from 2.5 EUR/MWh, to 1 EUR/MWh. In the 2040 scenario, the price differences are reduced from 12 EUR/MWh to 8 EUR/MWh. Swedish consumers benefit most from the increased capacity due to decreasing power prices in periods with low wind production and high consumption.

The results show that power flows towards Sweden in 70 per cent of the time. Today's situation is more balanced with about equal export/import. Most of the flows towards Sweden occur during the winter and the summer and towards Norway during the autumn.

Figure 19 Market benefits for 2030 and 2040

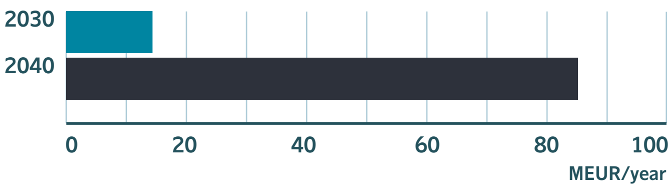
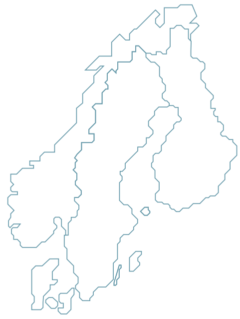


Figure 19 Average annual benefits for the Nordics in the 2030 and the 2040 scenario. The results are based on a simulation with a DC connection between Norway and Sweden.



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Uncertainty and sensitivities on market benefit
A common set of sensitivities were developed both in the 2030 and in the 2040 scenarios to capture relevant uncertainty and better understand the impact of changes in the important parameters. The focus has, however, been on the 2040 scenario, because the low benefits in the 2030 scenario, make it less interesting for sensitivity analysis.

In general, the results are very sensitive to changes in nuclear capacity and power prices. If 3,000 MW of nuclear power remains in the 2040 scenario, the benefits will be almost halved. Low power prices due to low gas and CO_2 prices have a similar negative impact. Increased capacity in the other Nordic corridors would lead to somewhat lower benefits as they partly fulfil similar needs. The largest impact comes from increased capacity between DK1 and SE3, which decreases the benefits with about 20 per cent. Higher power prices would lead to higher benefits.

The 2040 scenario is more uncertain, because the uncertainty increases over time. The uncertainty in the 2040 scenario is strongly connected to the nuclear decommissioning as well as the amount of other types of flexibility, which could be seen as a competitor to new power lines. Overall, the robustness in the results is weak due to changes in some of the most important drivers in the 2040 scenario.

Profitability is dependent on benefits after 2040
In this section, we present a simplified socioeconomic calculation based on the case with 1,000 MW of increased capacity, and a case with increased nuclear power in the 2040. The cost is based on a previously planned power line project "SouthWest Link",

Figure 20 Sensitivity Results

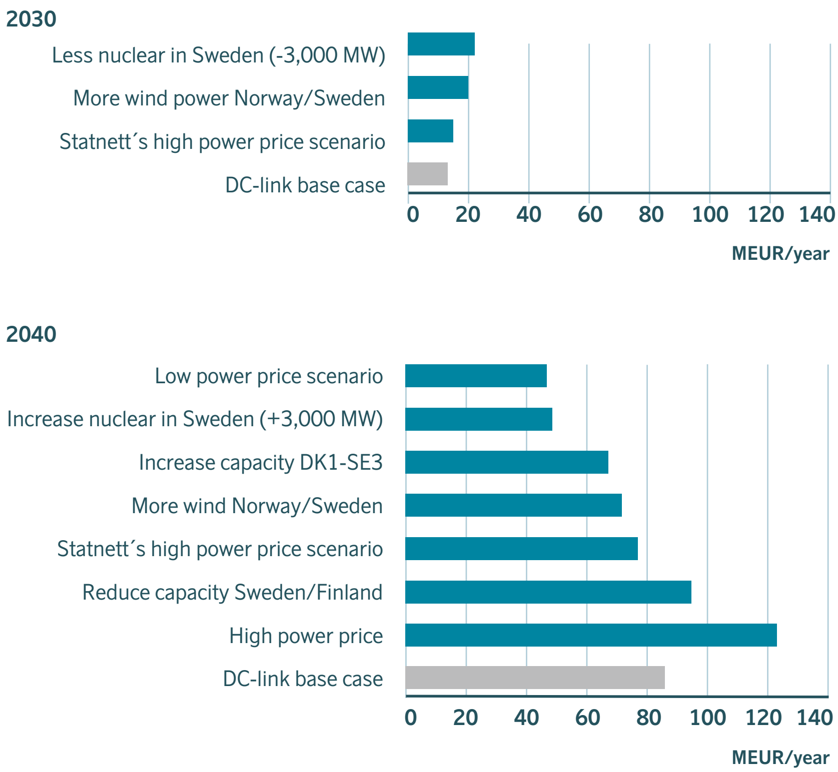
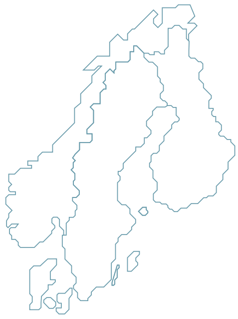


Figure 20 Annual Nordic benefits for the DC alternative. Base case is shown in grey. The sensitivity "more wind power Norway/Sweden" contains 12 TWh and 15 TWh increased wind power, respectively. In the "High power price" we have higher fuel prices, demand, increased renewables and CO_2 prices. Low power price scenario is a combination of Statnett´s and Svenska kraftnät´s results.



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which was estimated to around EUR 700 million in 2012, and does not include internal grid reinforcements. This estimate has a high degree of uncertainty but is still probably the best estimate at this stage.

The results indicate a positive net present value of increasing capacity by 1,000 MW between today's price areas NO1–SE3. If 3,000 MW of nuclear power remains in the 2040, the total NPV value will be negative. This illustrates the point that the benefits of 2040 are crucial for the NPV value, because the benefits in the 2030 are low. In addition, profitability is also sensitive to increasing costs. If the costs increase by 20–30 per cent, profitability would be negative.

Higher capacity utilisation and benefits with a DC connection
Model simulations have been done to investigate if there are any differences in the market benefit between an AC and a DC connection. The simulations indicate higher benefits for a DC solution, as a result of better utilisation of the total capacity from southern Norway. An AC connection may result in internal congestions in Norway, which would reduce the utilisation and the benefits. However, more thorough studies are needed to verify which is the most suitable technical solution.

As the more beneficial alternative in terms of market benefits, the DC alternative is the basis for further analysis in this study. However, this does not mean that a decision has been taken to implement a DC connection. More analysis and capacity calculations are needed to verify the best solution.

Next steps and future work
This analysis indicates relatively low benefits in the 2030. In addition, the positive net present value is dependent on the uncertain and distant 2040. Thus, the rational approach is to await possible future grid investments while monitoring the market development and update the study on a regular basis. For a potential future update, a grid study will be essential in deciding the extent of internal grid reinforcements needed. An equally essential component of future studies is the effect on system adequacy, as the analysis indicates very good potential during strained conditions in Sweden.

Figure 21 Net Present Value

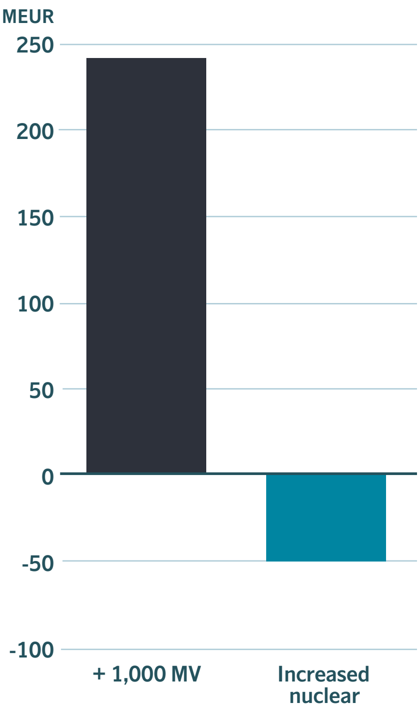

Figure 21 Net present values of +1,000 MW DC link between NO1 and SE3 and a sensitivity analysis with 3,000 MW increased nuclear power in Sweden 2040.

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6.3 Norway–Finland

6.3.1 Background and drivers

Norway and Finland are connected through a long 220 kV overhead line with low stability and restricted capacity. The motivation for investigating the Norway–Finland corridor is difficulties in controlling the local power flows as well as increases of both consumption and production on both sides of the border. Especially Norwegian petroleum activities are likely to increase their power consumption and there is excellent wind potential on both sides of the border.

Today, this interconnector is not treated as a market border on its own. There are ongoing discussions about how this corridor could be developed into a market border. It is important for the further development of the corridor that we have a functional market border between Norway and Finland. For this study, we have used as a base assumption that a market border is in place.

This interconnector differs from many other interconnectors by tying together smaller regions that have limited capacity to the larger national power systems on each side. Consequently, the common Nordic scenario, which is otherwise used as a base, needed to be supplemented with some local updates and sensitivities for different amounts of wind power and even some large consumption sensitivities on the Norwegian side were investigated. We call the adjusted dataset “2030 Reference”, and the results from this dataset are shown in Figure 23.

Figure 22 The Grid Topology of Nothern Norway and Finland

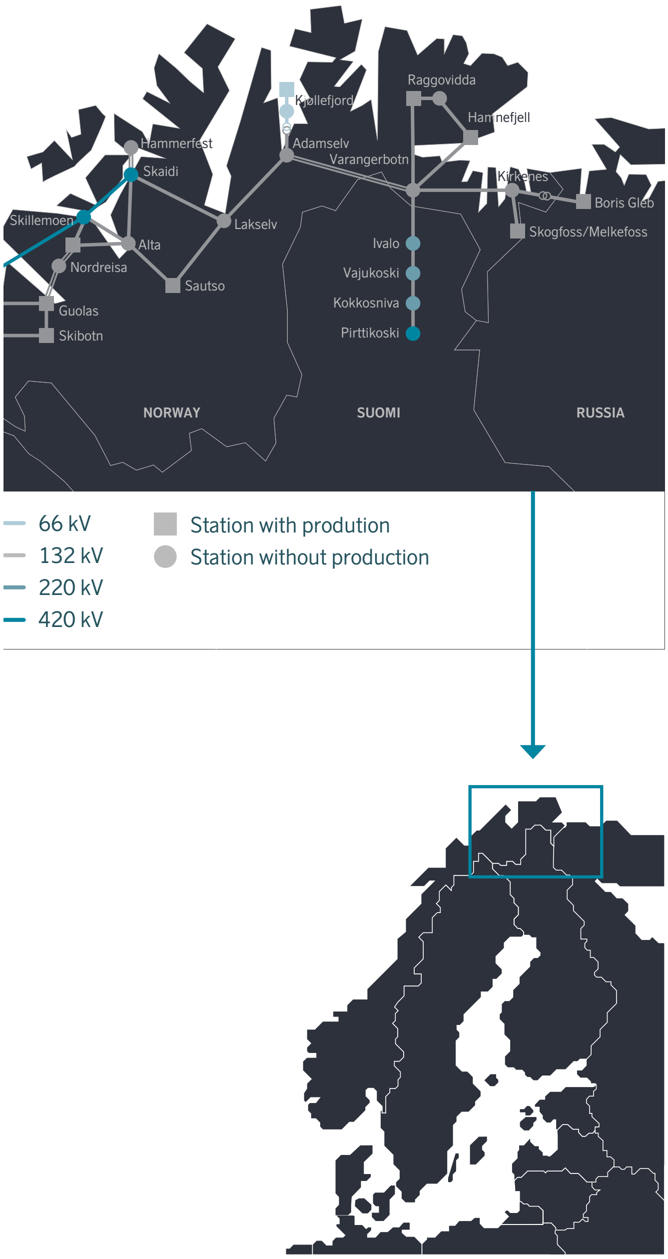


Figure 22 What we in the text refer to as East-Finnmark is from “Adamselv” and eastwards. Note that the geographical distances in Finland are much longer relative to Finnmark than indicated in the figure.

6.3.2 Outline of the study

Statnett and Fingrid have conducted both technical and market analyses of different connection alternatives between the countries. The technical analysis is especially important due to the long distances and resulting voltage and dynamic stability issues. Both parties have also investigated internal grid issues, which may or may not be affected by the development on the cross-border connection.

The main options we have looked at are:

- Maintaining the current solution
- Constructing a back-to-back station to increase controllability of the flow
- Building a 420 kV AC line to increase thermal capacity

We have used the PSS/E network analysis tool, the BID3.0 market model and Samnett in the analysis. However, because of very limited capacity for more production and consumption without grid investments on the Norwegian side, it is challenging to calculate the socioeconomic benefits. The common Nordic CBA is less suited in this case, where the possible cross-border investments also provide grid connection for consumption and production. Thus, we have focused on evaluating the advantages compared to the cost of the different options, without monetising the socioeconomic benefits.

6.3.3 Description of the Norwegian side

Finnmark is the northernmost county in Norway and the connection to Finland is located here. Statnett is currently constructing a 420 kV line into Finnmark, and when finished, it will go as far as Skaidi. This will provide more capacity, primarily for anticipated consumption growth from the petroleum industry in Hammerfest. However, capacity for additional consumption and production is still limited, especially in the eastern part of Finnmark. Between the 420 kV station in Skaidi and the crossing to Finland in Varangerbotn, there are still 300 km of 132 kV lines. The natural potential for further development of wind power in the area is very large and there are plans for additional consumption.

6.3.4 Description of issues on the Finnish side

In Finland, the current connection is a long 220 kV line, which is limited by stability issues, both voltage and dynamic oscillations. There are good conditions for wind power in northern Lapland, and some plans exist already. However, there are no plans for large increases in demand in this region, so any additional energy would need to be transmitted further south. Any possible increase in import from Norway would add to this surplus, thus requiring more grid reinforcements towards the south.

6.3.5 Results and conclusions

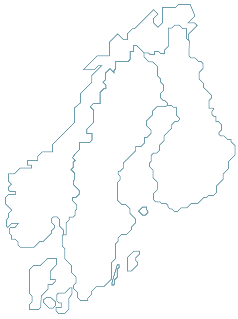
Maintaining the current solution

Maintaining the current solution would make it difficult to have any significant development of new production and consumption. However, the crossborder capacity itself is more limiting for the development in Finnmark than the north of Finland, as our simulations show that the future power flow goes from Norway to Finland more frequently than the other way. In addition, the lack of control over the power flow makes it difficult to make use of the existing capacity without dividing the grid in two separate radial parts, as the case has been for much of the time over the last years.

Back-to-back solution

The analysis so far shows that a back-to-back station with a moderate capacity would be a good solution. The main advantage of a back-to-back solution is that it makes it possible to utilise the existing lines better by controlling the flow. Our simulations show that controllability gives a larger total practical capacity, even when the available capacity at the border is the same in both cases. This is shown in Figure 23, where we see that a back-to-back solution with 120 MW of capacity makes it possible to utilise the capacity out of East-Finnmark much better. The lines out of East-Finnmark are Adamselv–Lakselv and Varangerbotn–Finland.

In addition, the controllability of a back-to-back solution helps stabilise the grid on both sides. It also would make it much easier to maintain the corridor as a market border in the daily system operation. Finally, it increases the security of supply in Finnmark as it is not necessary to divide the grid in radial parts in periods of high surplus.



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A main finding of the study is that the installed capacity of the back-to-back solution should be chosen with respect to the internal grid capacity in each country. The analysis indicates that a capacity higher than 120–150 MW increases internal congestions and thus may trigger large internal grid reinforcements in both countries.

420 kV AC solution

Based on the preliminary analyses, a solution of a long single 420 kV line does not seem to be a good option. Due to voltage and stability issues, the line will have low capacity. Additionally, lack of control over the flow makes the capacity difficult for the market to utilise and it easily creates bottlenecks elsewhere in the grid. A new line is also a very large investment, and it could require further large investments to prevent internal bottlenecks, which also has environmental effects.

A combination of the two options above may also be a solution, i.e. building 420 kV AC lines from both sides to the station and combine these with a larger back-to-back station. However, this would be an expensive solution and does not seem to be worth detailed consideration at this time.

Conclusions and further steps

This study indicates that a back-to-back solution of moderate capacity would be a positive solution. It facilitates increased trade and makes it possible to connect more wind power and consumption to the grid. We recommend that the back-to-back option be explored further.

Another result is that an AC loop connecting the 420 kV grids in Norway and Finland is not a good solution. This is the concept known as Arctic Circle in previous studies. Such a project would be costly, increase internal congestions in Norway and have limited capacity due to voltage stability. We have not investigated other large-scale alternatives.

In the next step, the socioeconomic, environmental and technical effects of this possible investment should be investigated. At the same time, there needs to be a plan to change the border into a normal market border.

Figure 23 Net Export from East-Finnmark

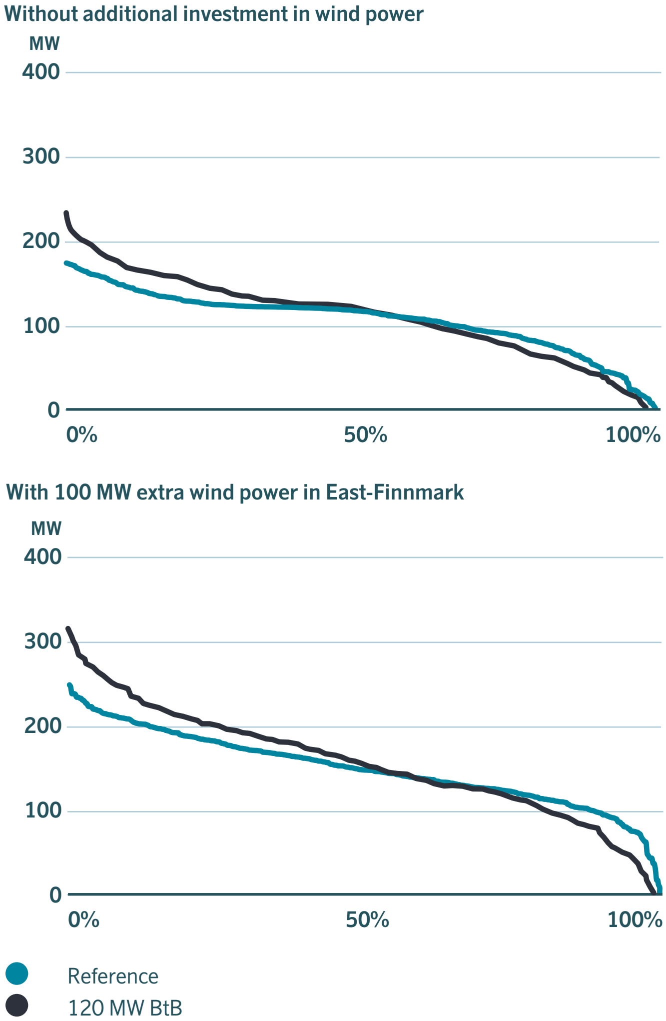

Figure 23 Export from East-Finnmark with reference and BtB, and 0 or 100 MW new wind. The flow out of the region is higher with BtB – which indicates a better use of the existing lines.

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6.4 Finland–Sweden

6.4.1 Background and drivers

The Finnish and Swedish TSOs conducted a joint study to investigate future cross-border capacities between Finland and Sweden, and the study was published in October 2016. The main result from that study was to increase the cross-border transmission capacity by adding a third AC-line between SE1 and Finland.

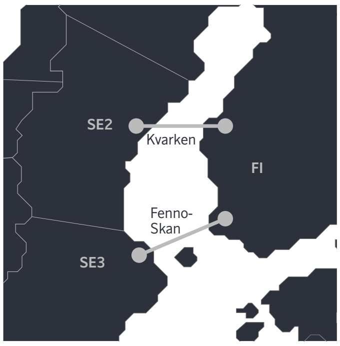
In addition, it was found to be beneficial to install a new HVDC connection between Sweden and Finland to replace the existing Fenno–Skan 1 cable. By 2029, that cable will have been operational for 40 years, which is considered the typical lifetime of an HVDC system. Of the HVDC alternatives, the Kvarken cable between SE2 and Finland was found to be technically more advantageous than adding a new cable to the Fenno–Skan connection between SE3 and Finland. However, due to uncertainties regarding the possible solution required to arrange a metallic return current path for Fenno–Skan 2, it was uncertain which alternative had the higher socioeconomic benefit.

As a conclusion, it was found necessary to have further studies concerning the Fenno–Skan 2 return current path, the technical and system related issues for the HVDC alternatives and to confirm the socioeconomic benefit. To continue those studies, this connection was chosen to be one of the bilateral studies in the Nordic Grid Development Plan 2019. The results of the study have also been published by Fingrid and Svenska kraftnät in a comprehensive bilateral report in April 2019, "HVDC capacity study between Finland and Sweden"[5 6].

6.4.2 Outline of the study

There are two HVDC alternatives to compare, the Kvarken alternative between SE2 and Finland and the Fenno–Skan alternative between SE3 and Finland, see Figure 24. Both alternatives are expected to have a capacity of 800 MW in this study, even though the size of the actual connection might be different due to available technology at the time of investment.

Figure 24 The Alternatives for the HVDC Connection Between Sweden and Finland



[5]https://www.epressi.com/media/userfiles/107305/1556599921/kvarken-hvdc-study-final-report-signed.pdf

[6]https://www.svk.se/contentassets/67111407548a4c54b767341ab0cfbbe3/hvdc_capacity_study_finland-sweden.pdf

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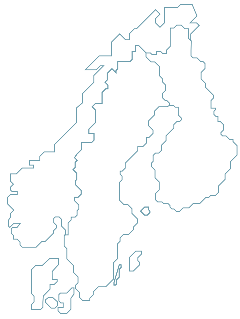
This study covered all relevant aspects, with special attention to the issues raised in the previous cross-border study. The grid studies were performed in order to compare the benefits of the Kvarken alternative and the Fenno–Skan alternative. A technical study with support from external cable design and manufacturing experts was prepared concerning the future of the existing Fenno–Skan cables. Route and permitting studies were performed for both alternatives.

Both HVDC alternatives were simulated in market models, one at a time, to estimate the impact on market benefits, which include the consumer and producer surplus as well as the congestion rent. Socioeconomic welfare was set against the estimated investment costs to get an indication of which grid alternative was the most beneficial. Finally, other factors specified to be included in the full CBA analysis were studied for both alternatives.

The study was made with an assumption that the Kvarken alternative is connected to the Swedish grid at the Hjälta substation, which is an important node in eastern SE2, meshing several 400 kV lines in the area. During the final stage of the study this was challenged as the routing from Hjälta to coastline would require a relatively long and rather expensive onshore connection through a demanding landscape. Another option could be to use the substation Stornorrfors, which is located much closer to coastline, but that will require additional grid studies.

6.4.3 Results and conclusions

Based on the grid studies, the Kvarken alternative is easier and more straightforward than the Fenno–Skan alternative. Furthermore, the Fenno–Skan 1 cable can still be used as a return cable for the Fenno–Skan 2 connection. The utilisation of the Kvarken alternative is not as dependent on the commissioning of other planned grid reinforcements compared to the Fenno–Skan alternative. Moreover, the Fenno–Skan alternative is not feasible without additional reinforcements as it is not possible to handle increased power transfer above 550 MW from Finland to Sweden due to fault ride through (FRT) issues on the Swedish side. On the Finnish side, there are some thermal issues which would require internal reinforcements.



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According to the route and permitting studies, both alternatives are realisable. With the Kvarken alternative, there are more challenges on the Swedish side, while the Fenno–Skan alternative is more difficult on the Finnish side. However, if the Kvarken connection point in the Swedish grid can be changed to another substation, from Hjälta to Stornorrfors, the routing difficulties in Sweden could be substantially reduced.

Market studies are based on power market model simulations, utilising the common Nordic scenario for years 2030 and 2040. All simulations were done in both Sweden and Finland to confirm the accuracy of the results, although the Swedish model results were used in further analysis due to shorter time resolution settings. In addition to the Nordic scenario, market studies were also extended with a set of relevant sensitivity cases.

According to the results, both alternatives have positive and rather equal net present value (Figure 25). The market benefits are mostly realised in the 2040 situation, while the benefits in 2030 are rather modest (Figure 26). This is because the benefits strongly increase with the increasing amount of wind power and the marginal price in Finland becoming higher during low wind situations. However, the change of the connection point in Sweden could reduce the investment costs for the Kvarken alternative significantly, up to 25 per cent, thus increasing the net present value substantially compared to the Fenno–Skan alternative.

Due to the late realisation of the market benefits, the recommendation is to follow the situation and evaluate the possibility to extend Fenno–Skan 1 lifetime beyond 2029, when Fenno–Skan 1 approaches the typical operational lifetime of an HVDC system (40 years). When more information is available, the study should be reviewed. Also, the market development compared to the assumptions in the Nordic scenario for the 2030 situation needs to be closely followed as well as the highlevel trends that affect the 2040 assumptions. Thus, the uncertainty in terms of benefits is reduced as well as the risk of the investment not being beneficial for the society. It is also critical to investigate what is the most beneficial connection point in Sweden for the Kvarken alternative when the study is updated.

Figure 25 Net Present Value

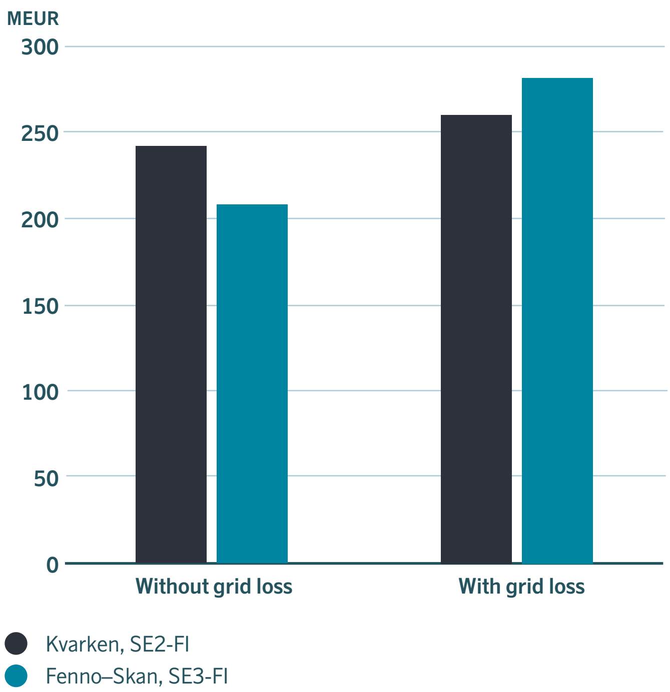

Figure 25 Net present value [MEUR] for the Nordics, including investment and maintenance cost, market benefit as well as grid losses.

Figure 26 Market Benefits for 2030 and 2040

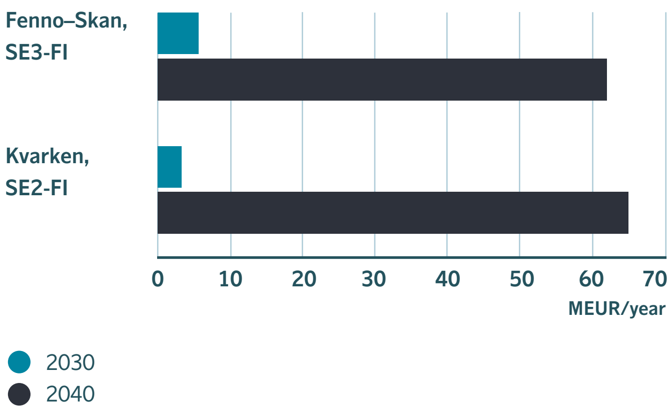

Figure 26 Nordic market benefit results for SE2–FI and SE3–FI for 2030 and 2040 reference scenario.

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6.5 Denmark–Sweden

6.5.1 Background and drivers

The corridor between Denmark and Sweden has been investigated as it links areas with hydropower (Sweden and Norway) with areas with high dependencies on wind and solar power. Both Konti–Skan 2 (HVDC link from bidding zone DK1 to SE3) and the southern Öresund cable (HVAC link from bidding zone DK2 to SE4) will be approaching the end of their expected technical lifetime around 2030. Therefore, it is relevant to investigate if it would be beneficial to renew or replace them.

6.5.2 Outline of the study

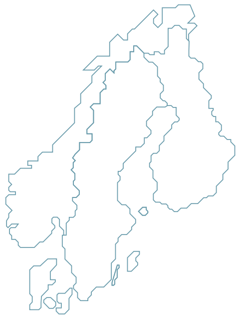
As the two cables, Konti–Skan and Öresund, will be reaching the end of their technical lifetime around 2030, these have been excluded from the reference scenario. The Swedish–Danish study has looked at four cases: reinvest in the current level of capacity, increase the capacity of DK1–SE3, increase the capacity of DK2–SE4, and increase both. The studied alternatives and the assumed transfer capacities are presented in Table 2.

Figure 27 Map of the Connections Between Denmark and Sweden

Table 2
Overview of the studied alternatives

NAME OF STUDIED ALTERNATIVE	DESCRIPTION	CROSS-BORDER CAPACITY [MW]			
		SE3 > DK1	SE3 < DK1	SE4 > DK2	SE4 < DK2
0_Ref	KS2 and northern Öresund cables are decommissioned	380	380	600	600
1_Today	KS2 and northern Öresund cables are renewed yielding today's capacity	680	740	1,300	1,700
2_SE3-DK1	Today's capacity is increased by 1,040/1,100 MW between DK1 and SE3	1,780	1,780	1,300	1,700
3_SE4-DK2	Today's capacity is increased by 600 MW between DK2 and SE4	680	740	1,900	2,300
4_All	Today's capacity is increased with both alternative 2 and 3	1,780	1,780	1,900	2,300

Table 2 Overview of alternatives in the study and the estimated cross-border capacity.



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The study is an early assessment and has focused on market simulations, market benefits and roughly estimated investment costs (excluding possible internal grid reinforcements), resulting in a preliminary net present value (NPV) calculation. Further analyses on the corridor should include permitting, routing and grid studies as well as additional aspects such as system adequacy, system stability and resilience, integration of renewable electricity etc., if possible. Furthermore, it has not been taken into consideration that Konti–Skan is a bipole as the costs of dealing with this are very uncertain and highly dependent on the technical solution chosen. The costs could be close to zero or as high as the cost for a new transmission HVDC cable. Also, all projects are commissioned in 2030 for easier comparison and calculations.

6.5.3 Results and conclusions

Svenska kraftnät and Energinet use different model set-ups to simulate the alternatives, which explains some of the differences in the results. Still, Figure 28 shows that all the investment alternatives are expected to have a positive net present value before including possible internal grid reinforcements.

In addition to the Nordic scenario, the analysis was supplemented with several sensitivity cases. The sensitivity cases investigate the impact from other studied corridors as well as impacts from variations of the Nordic scenario or alternative scenarios. Also, variations such as a shorter financial analysis period and doubled costs were studied. Four sensitivities decreased the NPV considerately: increased capacity between Norway and Sweden, increased nuclear power in Sweden 2040, lower fuel and CO_2 prices and using the market benefits from 2030 for both 2030 and 2040. On the other hand, increased fuel and CO_2 prices have a positive impact. Even though some sensitivities have a significant impact on the benefits, almost all cases still provide a positive NPV (except the “increased nuclear in Sweden 2040” –sensitivity for alternative 1).

From the results of this early assessment, it seems beneficial to maintain or increase the capacities between Sweden and Denmark. Therefore, it is suggested to study the possible alternatives in more detail. In continuation, extended grid studies will be necessary to identify any needed internal grid reinforcements, and confirm possible corridor alternatives.

Figure 28 Net Present Value

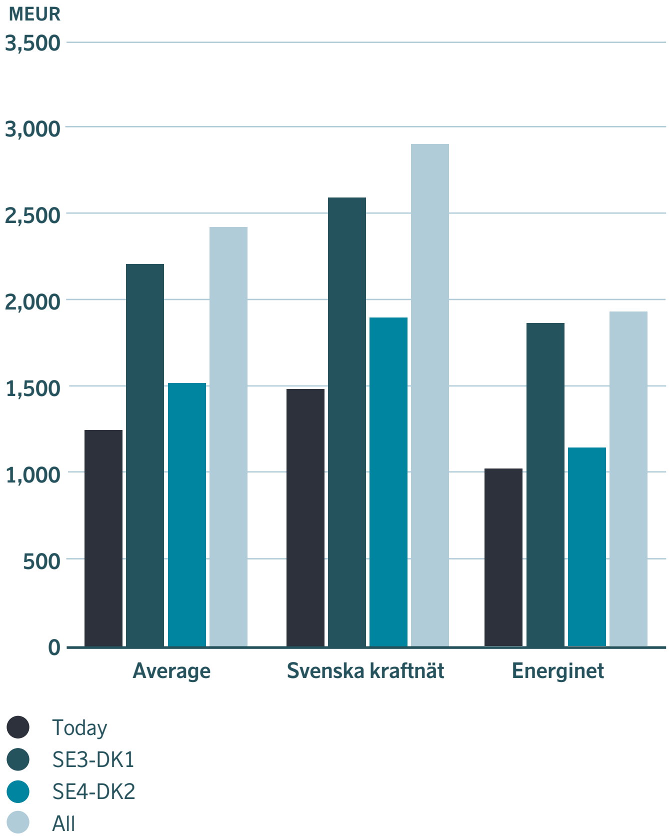

Figure 28 Shows the difference between the shown alternatives and the reference scenario in net present value.

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7 Further work

The Nordic Grid Development Plan will continue to be updated every second year, as part of the larger and more holistic cooperation described in the report "The way forward – Solutions for a changing Nordic power system". With a highly interconnected power system, it is necessary to have adequate coordination and transparency of grid development. Secondly, it is of high value to collaborate on data, forecasting and scenario work. In addition, a closer Nordic cooperation makes it easier to have an impact on the long-term analysis and grid planning within ENTSO-E. It is the ambition of the Nordic TSOs to further improve the cooperation on grid planning, studies and the joint effort within ENTSO-E.

The next NGDP will be published in 2021. As for the 2019 plan, it communicates an updated common Nordic view on the overall system development, the status of ongoing and planned investments of Nordic significance and a set of both common and bilateral studies relevant for future grid development. The exact scope of the next plan has not yet been decided. However, updated scenarios for market development, the overall need for more grid capacity north–south in the whole Nordic region and more interconnector capacity are all relevant topics for further studies. For the latter, in addition to the market studies presented in the current NGDP, grid studies must be performed in order to analyse the full benefit of the projects and to determine any needed internal grid reinforcements. Another issue that needs regional cooperation is study of security of supply, where it is important to analyse what potential there is for countries to support each other in situations of scarcity.

A significant part of the Nordic cooperation on grid development is about sharing knowledge and data on the overall future system and market development, both in the Nordic area and in Europe as a whole. As the European power system is becoming increasingly interconnected, each TSO needs to have a good understanding of the main features of European development, also in relation to its national grid development. In addition, this is a prerequisite for making consistent and sufficiently coordinated Nordic grid development plans. Thus, a closer cooperation on relevant scenarios, methods and data sets provides efficiency and increased quality both on the national and the Nordic levels. The future development of demand flexibility or storage is a topic of particular interest in this context, as it has a significant impact on both the benefit of future transmission investments and system adequacy.

The main goal and driver of grid development is to deliver value for producers, consumers and society as a whole. Hence, it is important that the process be transparent and that stakeholders be involved at an early stage. Involvement of stakeholders through workshops and transparent reports and other information will continue to be an important part of the further work on Nordic grid planning.

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8
Annex - Common evaluation framework

8.1 Introduction of a common evaluation framework

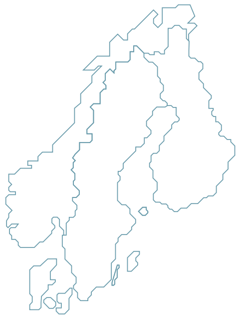
A Cost Benefit Analysis (CBA) is a systematic approach used to estimate the strengths and weaknesses of alternatives and thereby determine if an investment or decision is sound. The four TSOs have worked together to ensure a harmonised CBA framework for the evaluation of Nordic cross-border investments. The framework has been used in all bi-/multilateral studies for the Nordic Grid Development Plan (NGDP) in order to make the results transparent and comparable between studies.

In this NGDP, the CBAs have been done from a Nordic socioeconomic standpoint. In principle, this means that all relevant costs and benefits for the most important Nordic social groups have been included in the analysis.

The CBA framework is not intended to be used as basis for final investment decisions. This should be done by the TSOs themselves. The CBA framework aims to include those costs and benefits that are deemed most important and also possible to calculate/assess at the given stage of the project, rather than including all parameters. In some projects, not all factors will be relevant to assess, for example if the factor does not differ across the alternatives or if the factor does not have an impact on the specific project. It is up to the TSOs in each project to choose and motivate which factors are assessed and which are omitted. In principle, all costs and benefits included in this framework that can be expected to have a significant impact should be included in the analysis. The assessment is necessarily dependent on what stage the project under investigation currently is in, and the analysis will therefore be assessed according to the best available information in that stage.

Figure 29
Proposed CBA Structure

1	**Define the goals and objectives of the project**	Describe the current situation and future development. Identify current and future needs that the project will fulfill. List possible alternatives/actions that can meet the goals and objectives.
2	**Decide which alternatives to analyse in detail**	The analysed alternatives should be technically, economically and politically viable. The different alternatives should be compared to a situation where the existing grid is continued without new major investments (reference alternative). Major investments that are planned/decided but not yet existing should be included in the reference alternative.
3	**Predict outcome of cost and benefits over the relevant time period**	Focus should be on the delta value between the reference alternative and the development alternatives and on the effects that are deemed most important for the project's socioeconomic value. Calculate net present value for the analysed effects. It is however not all effects in a socioeconomic analysis that can be monetised in a clear and meaningful way. These non-monetised effects should instead be quantified in other terms or described qualitatively.
4	**Describe uncertainty and perform sensitivity analysis**	The result of the net present value calculations can be quite uncertain due to a number of reasons. Due to this the CBA should outline the parameters that are deemed most uncertain and which possible steps and actions that can be underdone to reduce the uncertainty. A sensitivity analysis can also be performed to analyse how the result depends on changes in key parameters.
5	**Compile the overall assessment**	The conclusion of the CBA will depend on both monetised and non-monetised effects together with uncertainty and the sensivity analysis.



8
Annex - Common evaluation framework

8.2 How to structure the CBAs

The value of a CBA will increase if it is well structured. It will make it easier for the decision makers to understand which premises and considerations the analysis is based on. In the following figure, a short proposal is given on how the CBAs can be structured.

8.3 Basic prerequisites

The scope of the analysis is for the Nordic countries, but Pan-European benefits are reported for discussion. The analysis shall be based on at least one scenario that is commonly accepted by the Nordic TSOs and at least two time steps shall be used in accordance with the scenario (in this case 2030 and 2040). The net present value (NPV) method is used with a 4 per cent real discount rate per year and the analysis period is 40 years based on a "normal" expected technical lifetime (25 years is used as a sensitivity analysis). Residual value is set to zero.

8.4 Monetised and non-monetised indicators

The figure below shows the main categories of indicators used to assess the impact of projects on the transmission grid.

Figure 30
Overview of Monitised and Non-Monitised Costs and Benefits

	COSTS	BENEFITS	
Monetised indicators	Investment costs	Market benefits	Transmission losses
	Operation costs	Integration of renewable energy	
Non-monetised indicators	Environmental and social impact	CO_2 emissions	Security of supply
			Flexibility and trade balancing

PROJECT ASSESSMENT

Figure 30 Overview of costs and benefits categorised in monetised and non-monetised indicators. The dotted lines indicate that integration of renewable energy and CO_2 emissions are partly included in market benefits.

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