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The Way forward –
Solutions for a changing Nordic power system

March 2018

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Content

Executive summary

This report summarizes the key solutions that are needed to meet the challenges affecting the Nordic power system in the period leading up to 2025. The report is based on the shared work of the four Nordic Transmission System Operators (TSOs) Svenska kraftnät, Statnett, Fingrid and Energinet. The publication will be updated every second year, and stakeholder events will be arranged to discuss the progress.

In 2016, the Nordic TSOs published the report "Challenges and opportunities for the Nordic Power System" which identified challenges within the five areas of system flexibility, transmission and generation adequacy, frequency quality and inertia. The present report is a common response, outlining coordinated solutions to these challenges.

The power system is becoming more complex and more integrated – cooperation both across country borders and between different stakeholders is a prerequisite for success. The solutions have been developed with input from stakeholders in the sector, and the common workshop hosted by the Nordic TSOs in January 2017 initiated this dialogue. The Nordic TSOs' objective with this report is to support further cooperation on energy policy and to provide our stakeholders with a transparent insight to the Nordic TSOs' projects and activities.

In order to provide an easy overview, the report is structured around roadmaps of the four areas; market, balancing, grid and ICT solutions, and a timeline that gives an updated view of the implementation process. Ch. 1, the introduction, gives an overview of the challenges and the types of solutions that the TSOs are working on, ch. 2-4 explains in more detail the four areas of solutions and ch. 5 discusses the way forward.

Market development. Common market solutions are key tools to ensure generation adequacy, efficient use of the power system, transparent investment signals, and competitive prices for consumers. Important solutions include a higher time resolution, sustainable balance pricing, a new common Nordic capacity calculation methodology and activation of the demand side.

Balancing of the power system. The current balancing model in the Nordic countries builds on controlling the frequency, which increasingly falls outside the limits. An important solution to meet this challenge is a new Nordic balancing concept called the modernized ACE, which the Nordic TSOs reached a cooperation agreement on in March 2018. The agreement covers the required development and operation of common IT tools for supporting common markets, i.e. the development of balancing products that enables harmonization with European platforms. A closer Nordic cooperation to strengthen operational security through the Regional Security Coordination (RSC) office is also an important solution.

Grid development. The Nordic TSOs have identified five main long-term drivers necessitating future Nordic grid investments: Further geographical integration, integration of renewables, Baltic integration, new consumption and the future development of the thermal and nuclear power. The future grid development is based on three principles; common prognosis/scenario, common methodology for cost-benefit analysis and bilateral analysis of corridors.

ICT solutions. Nordic R&D is very closely linked to the overall agenda of digitalization, Big Data and general IT innovation. The Nordic TSOs are commonly developing several IT tools and solutions that will enable an efficient functioning of both markets and system operation.

The way forward. A regional approach for developing the regulatory framework is needed to ensure that policies and measures are efficient, coherent, complementary and sufficiently ambitious. Preparing the Nordic power system to cope with the challenges ahead can only be secured in combining efforts on the three cooperation levels; energy policy, common system solutions and dedicated solutions.

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Introduction

The Nordic power system is currently undergoing the most substantial changes since the introduction of the common power market more than 20 years ago. The changes are driven by climate policy and technological development, and have led to a changing electricity generation mix with less thermal power and more small-scale, intermittent and distributed power. From 2010 to 2025, installed wind capacity in the Nordic countries is expected to quadruple to 24 GW, which corresponds to approximately 22 per cent of total installed capacity.

On the regulatory side, the ambitious project of creating a single European market for electricity is moving ahead. A central part of this project is a new framework, which harmonises the rules that govern all aspects of the European power system, while concurrently introducing new areas where Nordic cooperation is needed.

At the same time, new grid investments increasingly link the Nordic power system with the rest of Europe, and a digitalization generates more efficient solutions for steering demand and generation.

The result is a power system with new properties and challenges. These challenges are identified and described in the report "Challenges and opportunities for the Nordic Power System" published by the Nordic TSOs in August 2016. The report concludes that the main challenges in the period leading up to 2025 are:

- Meeting the demand for flexibility.
- Ensuring adequate transmission and generation capacity to guarantee security of supply and to meet the demand of the market.
- Maintainting a good frequency quality and suffient inertia in the system to ensure operational security.

With the goal of creating a cost-efficient, secure and green power system, the Nordic TSOs are dealing with these challenges by working on market, balancing, grid and ICT solutions.

Improved market solutions are meant to promote a competitive and efficient delivery of electricity to consumers. This requires solutions that will improve price and investment signals, reduce imbalances, and ensure adequate generation capacity.

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Introduction

In March 2018, the Nordic TSOs reached a cooperation agreement on a new Nordic balancing concept called modernized ACE (Area Control Error). The agreement covers the required development and operation of common IT tools for supporting common markets. The purpose is to make better use of common Nordic and European reserve resources as well as new technologies and market players, in order to ensure operational security. The new balancing concept and the joint Nordic Regional Security Coordination (RSC) office are important means to achieve efficient system operation.

Grid solutions are required for the efficient development of better market and balancing solutions, as the transmission capacity of the grid determines the physical limits. To ensure efficient coordination, the Nordic TSOs are currently developing common scenarios for a number of cross-border corridors in the Nordic power system, potentially resulting in new projects.

ICT solutions are necessary to enable the efficient functioning of both markets and system operation. Prioritized ICT solutions will enable market transactions as close to real-time as possible and advanced processing of power system data. The Nordic RSC office uses standardized power system data for a coordinated regional calculation of transmission capacity, as well as security and adequacy analysis. This allows the TSOs to operate the Nordic power grid more securely and closer to the limits.

As the power system becomes more complex and integrated, many of the solutions cannot be developed and implemented without extensive collaboration. Cooperation both across country borders and between different stakeholders in the Nordic power system is hence a prerequisite for success.

1 Introduction

1.1 Nordic cooperation on three levels

In practice, the solutions to the power system challenges are developed and implemented through cooperation on three levels:

1. **Nordic energy policy:** High-level political cooperation with a focus on issues such as subsidies, harmonization and generation adequacy. As an example, the report "Nordic Energy Co-operation: Strong today - stronger tomorrow", published in June 2017 by the Nordic Council of Ministers, targets this level. Participants are politicians, ministries, national energy regulation authorities (NRAs), top-management of industry, non-governmental organizations (NGOs) and energy companies.

2. **Common system solutions:** Broad cooperation on issues such as well-functioning power markets, security of supply and Nordic grid development. As an example the TSO report "Challenges and opportunities for the Nordic Power System" originate from this level. Participants are ministries, NRAs, market participants and TSOs.

3. **Dedicated solutions:** Technical cooperation on issues such as timing, alignment of processes and implementation of concrete solutions. The participants are the same as above but the work is more technical.

1.2 Roadmap of dedicated solutions

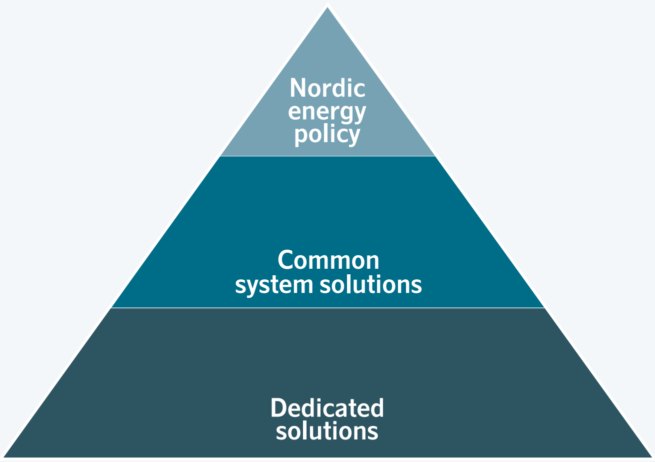
The individual projects presented in this report are dedicated solutions in their own right. However, when viewed collectively we move to level two cooperation. This report is the first of its kind to present a system wide overview of solutions the Nordic TSOs are working on in order to meet the future challenges for the Nordic power system.

In order to provide an easy overview, the report is structured around a Roadmap with four levels related to market, balancing, grid and ICT solutions, and a timeline that gives an updated view of the implementation process.

The objective with this report is to support the cooperation on energy policy and to provide our stakeholders with a transparent insight to the Nordic TSOs' projects and activities. The common workshop hosted by the Nordic TSOs in January 2017, initiated this dialogue. While the Nordic TSOs take the lead in developing these solutions, cooperation with and support from DSOs, market participants, regulators, and the political sphere is needed.

The intention is to up-date this publication every second year and organize stakeholder events to discuss the progress. Up-dated roadmaps will be provided for these events. In addition, stakeholder engagement on dedicated solutions will continue. Our ambition is to lift discussions up to a more Nordic (regional) level. The solutions are further elaborated in the following chapters in the report.

Figure 1. Framework for Nordic energy cooperation



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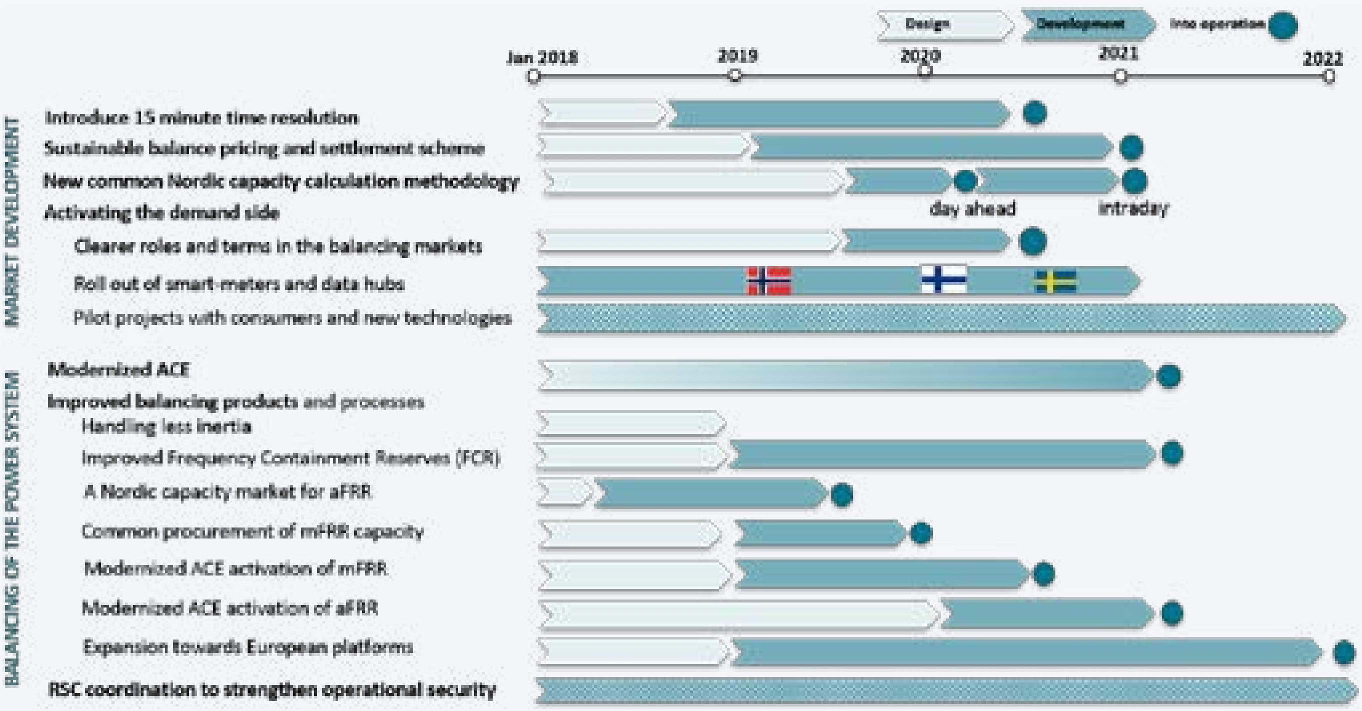
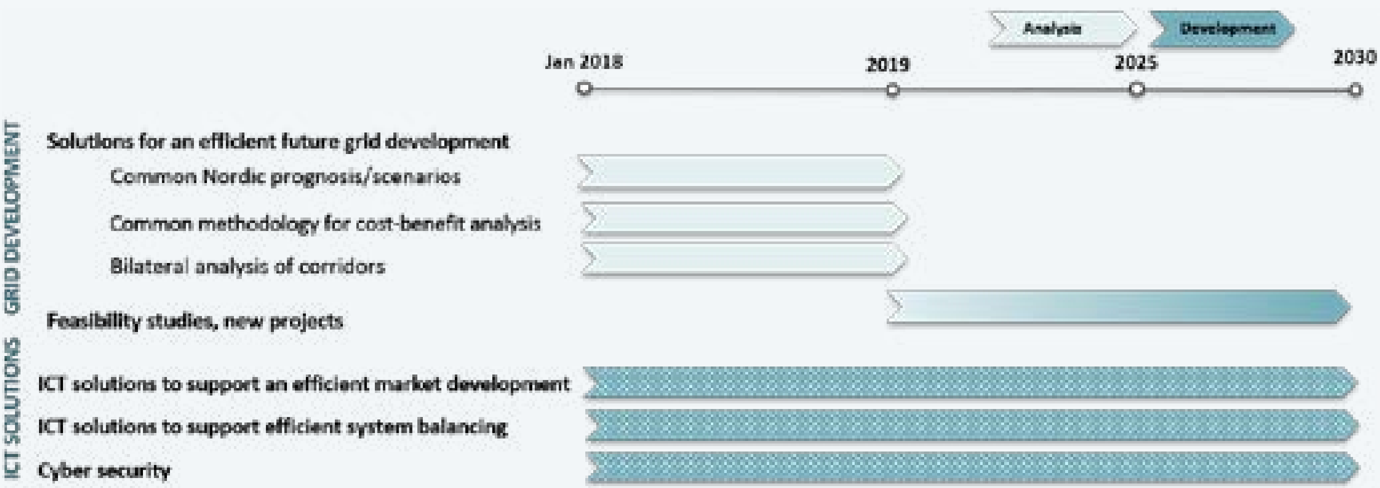
Introduction

Roadmaps for market development, balancing of the power system, grid development and ICT solutions





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Common market solutions are key tools to ensure generation adequacy, efficient use of the power system, transparent investment signals, and competitive prices for consumers.

With the current changes to the Nordic power system, new market solutions are required. From the TSOs perspective, an important part of this work is to ensure the continued coherence between market outcomes and the physical laws that govern electricity flows, in order to ensure efficiency and operational security. New market solutions are digitalized, as attested by the national Datahub projects and open data interface projects[1]. Such digital solutions are important for market participants whose information need is increased when markets and operating environment are rapidly changing.

In addition, with the transition to an electricity generation mix with larger shares of intermittent generation and the decommissioning of thermal power plants, the task of ensuring generation adequacy has been given additional attention. The following section elaborates on this aspect, while sections 2.2-2.6 present key market solutions.

2.1 Well-functioning power markets for ensuring generation adequacy

Generation adequacy is essentially a question of whether supply is sufficient to meet demand at all times. While the historical track-record is strong in the Nordic power system, the ongoing transition affects the balance due to changes in both power supply and demand.

In order to shed light on the generation adequacy effects of these changes, the Nordic perspectives on the pan European Mid-term adequacy forecast (MAF), which was published by ENTSO-E in 2017, have been elaborated in a Nordic MAF report. This Nordic MAF report confirms the known tightness in the Finnish system. However, it also indicates that the results in the European MAF report overestimates the problem by setting high outage rates for Finnish nuclear and thermal power plants. Sensitivity analyses in the Nordic MAF report shows that the supply to Denmark and south Sweden may also be vulnerable in very severe situations, depending on the future evolution of the power system.

The chosen sensitivity analyses in the Nordic MAF report include

[1] *Finland and Denmark launched new open data interfaces in 2017*

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additional developments in thermal capacity, Russian exchange, weather patterns, location of wind power and grid constraints. The analyses show that nuclear decommissioning and more extreme weather patterns are important drivers of the risk of load losses. The sensitivity representing low nuclear capacity in Sweden shows that generation adequacy will be challenged over time if not replaced by new sources of flexibility.

The Nordic TSOs believe that three principles should guide our approach to dealing with potential generation adequacy challenges. These principles are further discussed in "Generation Adequacy – methodology for assessment and market measures to secure it", which can be found in Appendix 1. First, generation adequacy challenges are most efficiently dealt with by facilitating well-functioning energy-only power markets, where the prices reflect the value of electricity at all instances. Second, in order to allow for a cost-effective use of the complementary patterns of intermittent renewable energy sources, as well as the trade of energy between surplus and deficit areas - especially in times of system stress - the Nordic TSOs must aim for adequate transmission capacity within and between the Nordic countries, as well as to neighboring regions. Third, time-restricted strategic reserves are preferred to market-wide capacity mechanisms, and only as a last resort if the energy-only market does not deliver a satisfactory supply-demand balance.

While the ambition of the current market setup is an energy-only power market along the lines of the three principles, a number of challenges have been identified. Many of these are presented in the reports "Challenges and opportunities for the Nordic Power System" published by the Nordic TSOs in August 2016, and in "Capacity adequacy in the Nordic electricity market", delivered to the Nordic Council of Ministers by THEMA Consulting Group in 2015.

In order to deal with these adequacy-related challenges, the TSOs have developed an Action plan, which was presented to Elmarknadsgruppen[2] in October 2017. The Action Plan outlines concrete solutions where this is currently possible, and common Nordic TSO ambitions in areas where additional constraints are currently present, e.g. in areas where European regulation is still under development, but open for Nordic influence. Many of the solutions/ambitions outlined in the report require NRA approval.

The Action Plan suggests to improve wholesale price signals by introducing a higher market time resolution (and imbalance settlement period), and by sending a clear signal to market participants that the Nordic TSOs are committed to the continual removal of barriers to correct price signals. This includes a reform in 2017 of the bidding rules for the strategic reserves in Finland and Sweden. In addition, the Nordic TSOs commit to work for a bidding zone structure that reflects structural congestions in the grid, and to improve the capacity calculation methodology to better manage grid constraints, but also to improve transparency of grid operations.

With respect to ancillary services and balancing markets, the Action Plan gives an overview of the work that the Nordic TSOs are currently involved with, such as the harmonization of product requirements, integration of markets, and the improvement of incentives for market participants to contribute to system balancing. Much of this work takes place on a European level.

In addition, The Nordic TSOs support the development of cost-reflective grid tariffs. In the coming years, several of the Nordic TSOs will review their current tariff structure.

While the Action Plan is publicly available, key topics are included and elaborated in the following sections in this chapter, and in Chapter 3 on Balancing. Many of the solutions require new ICT-solutions to enable efficient coordination and cooperation across the Nordic countries. This perspective is elaborated in section 2.6.

2.2 Introduce 15-minute time resolution

Introducing a 15-minute imbalance settlement period will reduce the magnitude of structural imbalances including those generated by ramping of interconnectors. Structural imbalances are a result of market design, rather than stochastic variations. With less structural imbalances, fewer reserves need to be activated. Figure 2 illustrates how a 15-minute imbalance settlement period reduces structural imbalances. The net energy is the same in both figures, but the figure on the right (with the higher time resolution of 15-minutes) also has a net energy balance within each sub-hour time-frame. In this illustrative case, imbalances are reduced by 75 per cent with the introduction

[2] Elmarknadsgruppen – The electricity market group – is a working group under the Nordic Council of Ministers that intends to further improve the general conditions for the electricity market in the Nordic Region.

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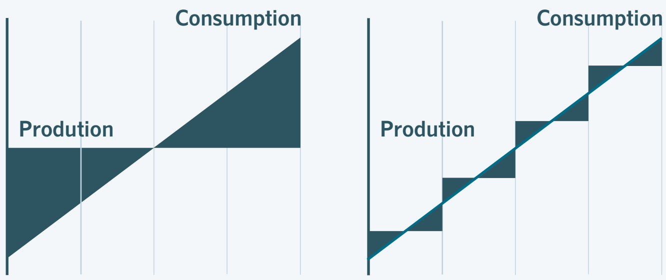
of a 15-minute resolution. However, achieving this is only possible if the market actors are able to trade away these structural imbalances in a 15-minute intraday market as market participants need to face correct incentives through 15-minutes imbalance prices as well. The time resolution in the balancing market should hence be changed to 15-minute in parallel with 15-minute imbalance settlement period and 15-minute intraday market.

Figure 2. Illustration of how a 15-minute market reduces structural imbalances



Introducing a 15-minute time resolution will also provide new market opportunities for consumers and generators and allow for increased transmission utilization, which ultimately can lead to reduced tariffs. In addition, it will improve the accuracy of incentives faced by market participants.

The Guideline on Electricity Balancing requires TSOs to apply an imbalance settlement period of 15-minute no later than December 2020. The Nordic TSOs have agreed on a common project to implement a higher time resolution, and the ambition is to implement a 15-minute imbalance settlement period and a 15-minute resolution in the balancing and intraday markets by July 1st 2020. Introducing a 15-minute time resolution in the day-ahead market is an ambition in the longer run.

2.3 Sustainable balance pricing and settlement schemes

Correct incentives for market participants to stay in balance are important to achieve generation adequacy and efficient markets, and the imbalance price is the most important incentive given to market participants to trade themselves in balance. Efficient balancing from a socio-economic point of view implies that the imbalance price should equal the marginal cost of balancing. In scarcity situations, balancing is costly. This means that imbalance prices should be allowed to develop to be very high and cost-reflective – including in scarcity situations. As the imbalance settlement period will also be reduced, very high imbalance prices will – all else equal – affect a smaller aggregated energy volume.

In practice, the methodology for pricing imbalances is under review. A common Nordic TSO project has analyzed how to improve incentives to market participants by looking at scarcity pricing, harmonization needs and implications from the inter–TSO settlement.

2.4 New common Nordic capacity calculation methodology

Transmission capacity calculations are a fundamental input in the common power market as they determine the market size. Physically, transmission capacities express the upper limit of how much power that can flow between bidding zones. While the TSO objective is to allocate as much transmission capacity as is socioeconomically efficient to the markets, the allocation must take into account the physical limitations of the grid, including outages and potential faults.

Capacity calculations in the Nordic power system will be coordinated through the Nordic RSC and enhance cooperation among the Nordic TSOs. This will make it possible to utilize existing transmission capacity between bidding zones more efficiently, while at the same time maintaining operational security. In turn, this will lead to more trading possibilities in the power market.

The work on new capacity calculations originate with the Guideline on Capacity Allocation and Congestion Management (CACM), which requires the development of more regional cooperation and the establishment of a common calculation methodology. The default requirement is a Flow Based methodology, which takes into account that electricity flows in AC-grids are not under control by the TSOs, but by the laws of physics. An alternative methodology is the Coordinated Net Transfer Capacity (NCTC) approach, which resembles the current methodology.
The Nordic TSOs have submitted proposal for a new methodology

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to the regulators in September 2017. Implementation of the new methodology in the day-ahead market is planned for mid-2020.

2.5 Activating the demand side

A more responsive demand side would bring benefits, such as reducing the probability of extreme price spikes in the day ahead market, and more flexibility could be made available to the intraday and balancing markets, i.e. a cheaper way of balancing the system. The technical potential for demand side response is big, much of which may be realized without great costs or substantial structural changes. In the balancing markets operated by TSOs, it is of particular relevance to get new participants to enter the market to make up for the loss of thermal power plants.

When discussing the provision of demand side response, it is important to distinguish between different types of consumers. While the flexibility of large-scale industrial consumers is already utilized to some degree in the Nordic countries, the retail consumer is largely a passive player. Currently, most retail consumers have contracts with fixed energy prices, or contracts where the price is variable, but the consumptions is settled based on a generic demand pattern. In turn, there is little incentive to participate in markets for the demand side. Industrial consumers face different entry barriers than retail consumers, and these differences have to be taken into account when designing markets and policies.

Much of the demand response potential is connected at the distribution grid level. Through the Clean Energy Package, the European Commission aims to promote increased regulation of the distribution grid and DSO activities. The Nordic TSOs welcome a strengthened role of the DSOs, and believe that closer TSO-DSO cooperation is beneficial in relation to making the retail customer an active player in the power markets.

In practice, the Nordic TSOs currently work on three types of solutions to activate the demand side:

Clearer roles and terms in the balancing markets: The Guideline

Table 1. Overview of Nordic pilot projects enabling aggregation (installed and planned)

What?	Where?	2016	2017	2018
Demand response pilot	NO4 in Norway			
Enabling aggregation of bids in 10MW volumes in mFRR	NO1 in Norway		X	
Enabling aggregation of bids in 5MW/10MW volumes in mFRR	NO1 in Norway			X
Large scale demand response pilot	NO4 in Norway			X
Pilot of flexible households in FCR-N	SE3 Sweden	X	X	
Pilot of demand side response/ energy storage in FCR-D	SE3 Sweden		X	X
Demand response pilots in different balancing products	Finland	X		
Pilot of independent aggregator and multi-BRP aggregation in FCR-N	Finland	X		
Independent aggregators and multi-BRP aggregation allowed in FCR-D	Finland		X	
5 MW bid size in mFRR	Finland		X	
Aggregation of generation and load in mFRR	Finland		X	
Pilot of independent aggregator and multi-BRP aggregation in mFRR	Finland			X
Independent aggregators and multi-BRP aggregation allowed in FCR-N	Finland			X
Electric vehicle validation for FCR-N	Denmark	X	X	X
Heat pump project testing e.g. sub-meter and hub communication	Denmark	X	X	
Battery project testing mFRR	Denmark	X	X	
Flexibility from industries developing measurements, baseline, pricing etc.	Denmark	X	X	X

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on Electricity Balancing introduces the role of Balance Responsible Party (BRP) and requires TSOs to set national terms and conditions related to balancing. The Clean Energy Package is foreseen to set guidelines for the design of aggregator solutions. Clarifying the roles required to maintain security of supply, allow for increased efficiency in the balancing markets and setting terms for aggregated bids, will make it easier for market actors to participate in balancing and increase the number of available resources. Well-functioning markets with a high level of competition should in the long run provide lower costs for total reserves and allow capacity to be used where it benefits most.

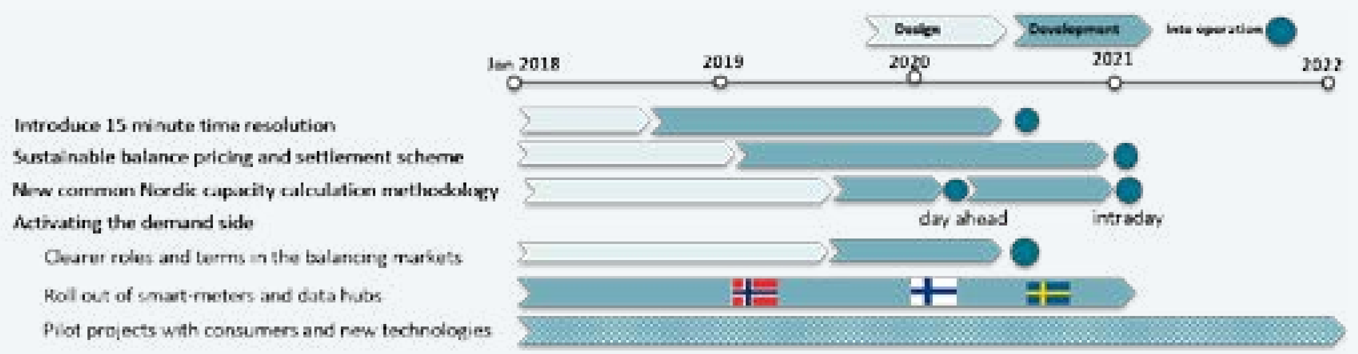
Roll out smart-meters and data hubs across the Nordic region: This is a fundamental prerequisite for the activation of consumers. With the introduction of smart meters and retailers offering contracts with hourly (or perhaps 15 minute) settlements, consumers are given the choice to expose themselves to more price variation, and thereby save costs by optimizing their consumption patterns. As an essential step in solving data access, national data hubs in the Nordic countries are either under development or already in operation. These hubs will provide easy and equal access to consumer data, and will facilitate a transparent and neutral retail market where consumers can make efficient and informed decisions, and where suppliers and third parties can develop innovative services. Looking ahead, linking the Nordic data hubs together could ease the exchange of data across national borders and facilitate an integrated Nordic retail market. With an integrated market, competition for both new and existing market participants will increase, which will benefit Nordic consumers.

Pilot projects with consumers and new technologies: These projects test the barriers to demand side participation. An important part of this is to enable aggregators to open the market for smaller resources. Allowing third parties to aggregate multiple loads and offers will increase flexibility in the market. The recently published paper "Unlocking flexibility – Nordic TSO discussion paper on third party aggregators" discusses this further. Table 1 provides an overview of recent pilot projects.

2.6 ICT solutions to support an efficient market development

The Nordic TSOs are adapting the markets to the European platforms, which implies harmonized rules, processes and information exchange. An adaptation will enable market participants to trade on a pan-European level, but it will also require more data. A close TSO and DSO collaboration will therefore be essential in order to handle large quantities of data and making them available to stakeholders in the most efficient way. In addition, the rapidly changing operating environment in the power markets also increases the need for information. Open data interfaces are one way of making relevant power system information easily available to market participants for carrying out market analyses for trading purposes. In Finland and Denmark open data interfaces were launched in 2017.

Roadmap for the market solutions



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Balancing of the power system – closer collaboration and customized services

While wholesale power markets ensure the planned balance of supply and demand, they do not ensure operational security of the power system in real-time. This falls on the Nordic TSOs, who are responsible for balancing consumption and generation at every instant. In a secure state, the power system can handle any single fault without resulting in a blackout or involuntary disconnection of demand. The current balancing model in the Nordic countries builds on controlling the frequency and the trend is that the frequency increasingly falls outside the limits, as illustrated in Figure 3. This trend needs to be reversed to ensure operational security of the power system – the system requires more activation, smaller bid-sizes and more automatization.

The current Nordic balancing model also lacks the prerequisites for taking advantage of the ongoing European harmonisation in the balancing area. This could bring wider balancing markets to the Nordic Region, enabling a cost-efficient use of resources within the region by increasing the trade of flexible resources with Continental Europe. The Guideline on Electricity Balancing includes a harmonization package of standard products and introduces common platforms for exchange of balancing products. This will affect the balancing process and the products in the Nordic region.

3.1 Modernized ACE – a new balancing concept

The new Nordic balancing concept involves a transition from controlling the frequency to an ACE (Area Control Error) based concept similar to Continental Europe. Compared to the standard ACE based operation, the new concept will apply cross border activation of imbalance netting and balancing reserves (aFFR and mFFR). We call it modernized ACE. The concept builds on controlling the balance in individual bidding zones, as illustrated in Figure 4, while using powerful ICT solutions. This will enable efficient netting of imbalances and trade between bidding zones, while considering network constraints all the time.

The new balancing concept will allow for a more efficient activation, smaller bid-sizes and more automation. While ensuring clear roles and responsibilities among balancing participants, the main benefits from the new balancing concept include better opportunities for harmonization with and participation in the forthcoming European balancing markets and a more efficient procurement of balancing

Figure 3. Frequency deviations 2003-2017

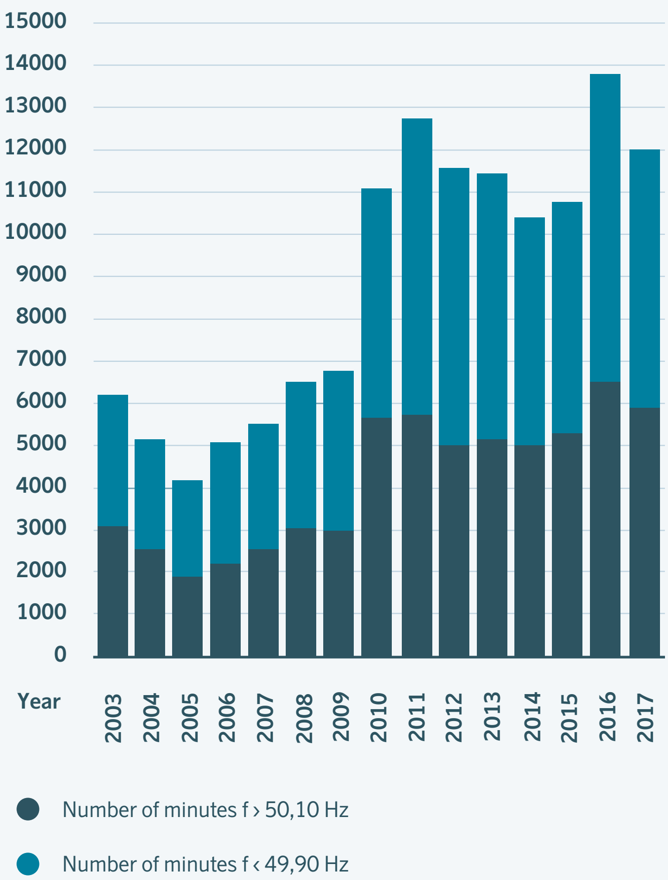
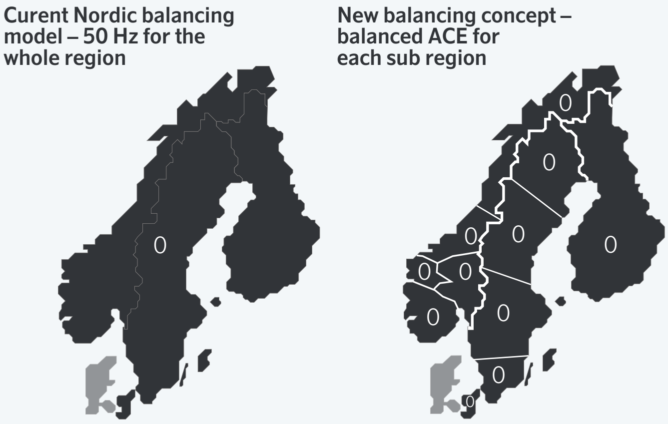


Figure 4 . Illustration of the new balancing concept



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products[3]. Furthermore, the new balancing concept improves frequency quality. Each of these elements contribute to an increased security of supply.

Continued development and implementation of the new balancing concept means comprehensive work during the gradual implementation over the next four years, not least because of necessary new ICT solutions. In order to ensure an efficient process, stakeholders will be engaged throughout the process.

3.2 Improved balancing products and processes

The balancing services in the Nordic countries consist of several products: Frequency Containment Reserves (FCR)[4], automatic Frequency Restoration Reserves (aFRR) and manual Frequency Restoration Reserves (mFRR). These are activated to contain and restore the frequency. Until the FCR has been activated, the inertia response and system damping reduce the frequency drop below unacceptable levels. The FCR is restored when the aFRR and mFRR have been used.

Figure 5 explains the present balancing services in the Nordic countries. The development of a new Nordic balancing concept involves the creation of new balancing products, and the improvement of existing ones. This section presents a progress overview for selected products.

Handling less inertia

Inertia (rotating mass) is vital to ensure stability in the power system. In the future, a larger part of the generation mix will produce power without simultaneously providing inertia. Furthermore, import on HVDC-lines do not contribute with inertia. Therefore, situations with large imports to the Nordic system can result in insufficient amount of inertia in the system. A power system with low inertia will be more sensitive to disturbances, i.e. have smaller margins for keeping frequency stability. This is not satisfactory.

As the Nordic TSOs have the responsibility to ensure that the power system is secure enough to handle system disturbances, new solutions are being developed to ensure there is enough inertia in the system at all times. While they are work-in-progress the focus is to:

Figure 5. Frequency before and after an event

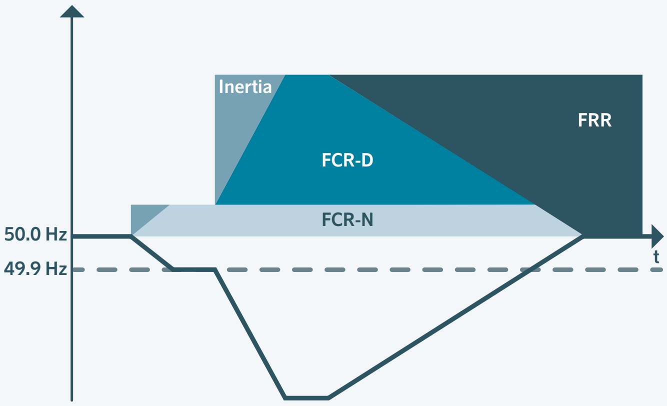

Figure 5. The graph illustrates the frequency before and after an event (e.g. loss of production). It shows the relation between balancing services that are activated to contain and restore the frequency. FRR includes both aFFR and mFRR. The role of the inertial response is indicated.

- Implement simple and robust remedial actions for handling low inertia situations. Within this, explore the possibilities for new, faster frequency reserves. However, until these are in place, limiting the size of the largest possible disturbance (i.e. lowering the output of the largest generation units connected to the Nordic power system) may be needed to handle low inertia situations.
- Improve situational awareness with a more accurate real-time estimation and a tool for forecasting inertia.
- Develop cost-efficient long-term measures to ensure adequate inertia and system security.

Analysis indicates that a market solution for ensuring a certain level of inertia in the system is not the most efficient solution for the Nordic system at the time being within the 2025 time horizon.

Improved Frequency Containment Reserves (FCR)

To meet the future requirements of the power system the technical specification of FCR needs to be adjusted to ensure operational security in both normal and alert state operation. Finding a more optimal specification for FCR requires a trade-off between system needs and sufficient participation in the market. Potential solutions include:

[3] This includes a more efficient and increased procurement of automatic frequency response reserves (aFRR) – capacity and energy - and a common Nordic procurement of automatic and manual FRR capacity, with daily dynamic reservation of transmission capacity between bidding zones.
[4] FCR contains two different products – FCR-N (Frequency Containment Reserves for Normal operation) and FCR-D (Frequency Containment Reserves for Disturbances)

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Balancing of the power system – closer collaboration and customized services

- The development of a joint Nordic frequency quality target reflecting the target for system security.
- A fine-tuning of the FCR requirements based on feed-back from stakeholders.
- Implementation of a Nordic FCR market.

New Nordic market for aFRR

Introducing a common capacity market for aFRR in the Nordic power system is a corner stone in the new balancing concept. With the introduction of common Nordic aFRR capacity procurement with daily dynamic reservation of transmission capacity between bidding zones as well as cross-border activation, the availability of balancing resources is expanded. This will improve the flexibility in the Nordic power system. The new Nordic balancing concept will also introduce the option for market participants to provide voluntary aFRR bids close to real time.

This is a needed step towards harmonization with Continental Europe, and it improves the opportunity for the Nordic countries to take advantage of the coming European PICASSO platform for aFRR energy activations.

Common Nordic procurement of mFRR capacity

In addition to aFRR, the new balancing concept introduces common Nordic capacity procurement of mFRR – also with daily dynamic reservation of transmission capacity between bidding zones.

Modernized ACE activation of mFRR

The first major milestone in the implementation of the modernized ACE balancing concept is the introduction of a new activation method for mFRR activation. In ACE operation, each TSO will be responsible for activating mFRR for their own LFC areas (bidding zones). The TSOs will for every 15-minute period request a volume per LFC area, and will eventually use the new European standard products for balancing energy. A central Activation Optimization Function (AOF) will secure an optimal use of the cheapest bids and an efficient and safe use of available transmission capacity.

This development is in line with the European development with common platforms for balancing energy activation. When the European platform, MARI, is put into operation, the Nordic countries will be part of a European market for mFRR activation.

Modernized ACE activation of aFRR

The implementation of the modernized ACE concept is completed by the new energy activation market for aFRR. Each LFC area (bidding zone) will have their own aFRR controller regulating the power balance in the area, including energy bids for aFRR and price based activation, according to a Merit Order List. A central Activation Optimization Function (AOF) will secure optimal use of the cheapest bids and effective and safe use of available transmission capacity.

This development is in line with the European development with common platforms for balancing energy activation. When the European platform, PICASSO, is put into operation, the Nordics will be part of a European market for aFRR activation.

Expansion towards European platforms

The introduction of common Nordic capacity procurement of Nordic mFRR will expand the mFRR market. The Nordic TSOs are working on improvements, such as electronic activation of bids, which will open the market to more participants by allowing lower minimum bid size. In the future the Nordic platform will also connect to the European MARI platform for the activation of mFRR energy. The Nordic TSOs have not yet taken a position on the potential use of the European TERRE platform for exchange of the slower Replacement Reserves (Activation time of 30 min).

3.3 RSC coordination to strengthen operational security

The new generation patterns lead to increasing and more fluctuating power flows across Europe, and hence an increased need for closer coordination in the daily operations of the power systems.

The Nordic TSOs respond to this development through enhanced coordination and operational collaboration in all timeframes of operational planning and daily operation. The newly established Nordic Regional Security Coordination (RSC) office is a cornerstone in this Nordic TSO cooperation. The RSC office will provide five core services to the TSOs in the operational planning phase and support the TSOs to optimize the

[5] *PICASSO stands for Platform for the International Coordination of the Automatic frequency restoration process and Stable System Operation"*

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Balancing of the power system – closer collaboration and customized services

daily operation of the national power systems, see figure 6.

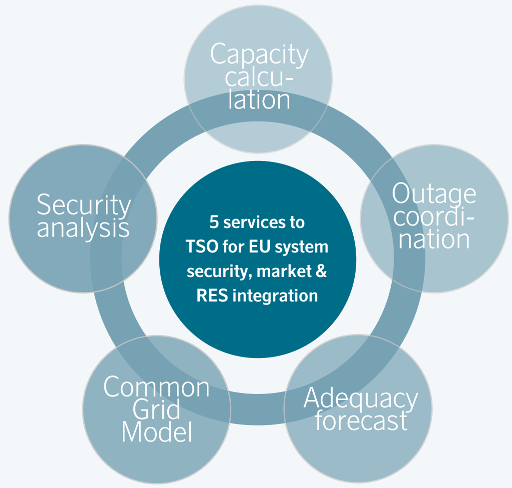
The Nordic TSOs agree with the European Commission on the direction of closer cooperation between TSOs. Continuous capacity calculation and additional coordinated regional system analysis are likely to be developed to support TSO decision-making processes. Experiences gained from the implementation of the first regionally coordinated services in the Nordic RSC will help guide future improvements in regional TSO coordination.

3.4 ICT solutions to support efficient system balancing

The new balancing concept requires substantial developments in the area of ICT and digitalization, although many of the IT tools are for internal use. The Nordic market for aFRR, however, requires a new platform for the market participants in order to facilitate cross-border trade in the Nordic region closer to real-time. More generally, the harmonisation of modernized ACE with the balancing models of Continental Europe involves advanced ICT solutions to ensure efficient coupling with European exchange platforms such as PICASSO, MARI and TERRE. This includes the creation of common market modules and near real-time systems for awareness and forecasting.

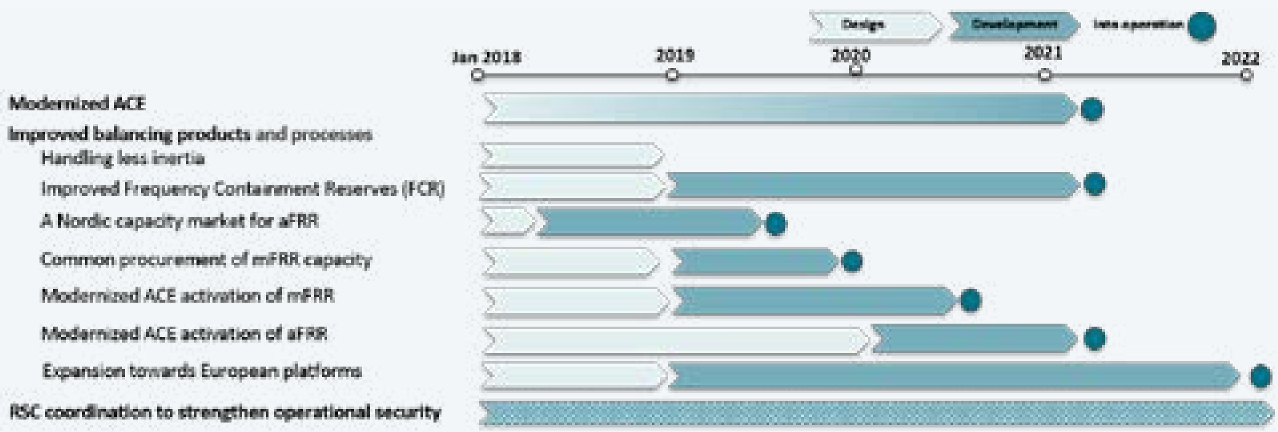
The RSC office contributes to maintaining security of supply in the Nordic region by exploiting the standardized data models for the European power system. New ICT solutions using these large quantities of data allow for regionally coordinated calculations and analyses of grid security and capacities.

Figure 6. Services provided by the Nordic RSC office



The TSOs physical (grid management and operation) and digital worlds will become intertwined as information about the physical assets can be made available anywhere. One of the more promising developments is the emergence of data and analytics tools that can be used to find, manage and analyze data from operational technology, for business purposes. The IMPALA project, which is more detailed explained in chapter 5.3, is an example where the combination of artificial intelligence and big data is used to forecast imbalances, which allows market participants to optimize their business.

Roadmap for the balancing solutions



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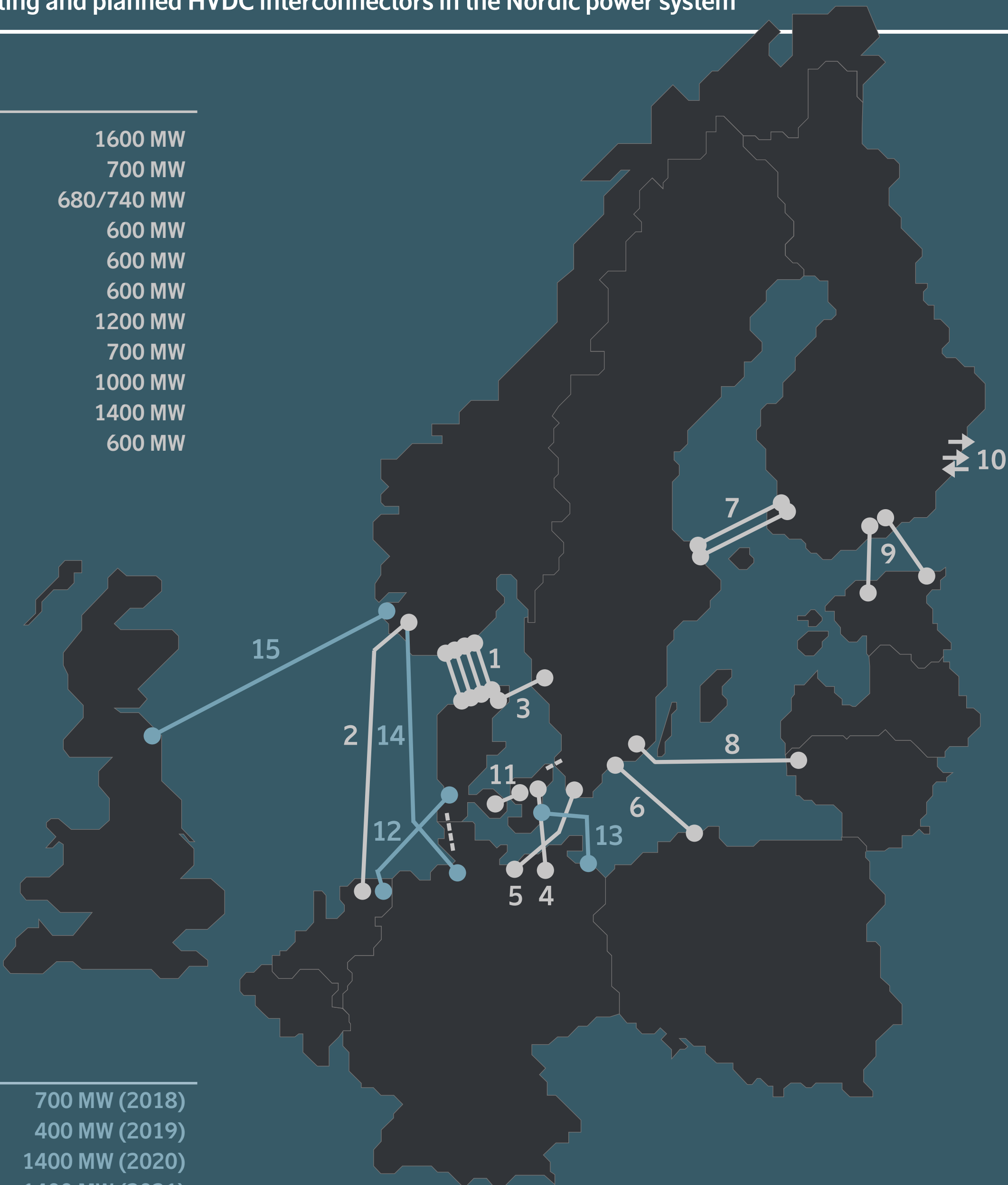
Grid development – planning with a regional focus in a European context

Figure 7. Overview of existing and planned HVDC interconnectors in the Nordic power system



Existing

1 Skagerrak 1–4	1600 MW
2 NorNed	700 MW
3 Konti-Skan 1–2	680/740 MW
4 Kontek	600 MW
5 Baltic Cable	600 MW
6 SwePol Link	600 MW
7 Fenno-Skan 1–2	1200 MW
8 NordBalt	700 MW
Estlink 1–2	1000 MW
10 Vyborg Link	1400 MW
11 Storebaelt	600 MW

Under Construction

12 Cobra	700 MW (2018)
13 Kriegers Flak	400 MW (2019)
14 Nord Link	1400 MW (2020)
15 North Sea Link	1400 MW (2021)

Under development

Viking Link
DK West – Germany
North Connect
Hansa PowerBridge

Only those with a final investment decision are included in the map.

4

Grid development – planning with a regional focus in a European context

Strong transmission networks facilitate a cost-efficient transition to a green power system, as they enable an efficient cross-border utilization of power production. In addition, they enable the exchange of system services, and remain a prerequisite for ensuring a further integration of markets.

4.1. Current grid development

As outlined in the Nordic Grid Development Plan 2017 (Appendix 2) large amounts of new renewable generation are expected to be built in the Nordic countries, especially in the northern parts of Sweden and Finland. This will significantly increase the north-south flows. In order to facilitate an efficient transmission of the energy surplus in the north to the consumption centers in the south, new transmission lines are needed. In addition to new lines within the Nordic region, planned new HVDC-lines will strengthen the integration of power markets towards Continental Europe and UK.

The Nordic Grid Development Plan shows that ongoing and near-future investments in the Nordic grid are at a historic high, cf. figure 8. The main drivers behind this development are the integration of renewables, further integration towards other synchronous areas, the need for a sufficient level of security of supply, and the need for reinvesting in an ageing Nordic grid.

The high investment levels across the Nordic TSOs reflect investments within Nordic countries, as well as cross-border projects. The cross-border projects in the Nordic Grid Development Plan 2017 are shown in Table 2.

While allowing for increased trade within the Nordic region and with Continental Europe, large HVDC-lines also challenge the system operation because of large variations in power flows from one hour to another. Market design changes such as higher time resolution in wholesale power markets, cf. section 2.2, are necessary to mitigate this challenge and to contribute to the efficient use of the grid.

Figure 8. Total investments by the Nordic TSOs

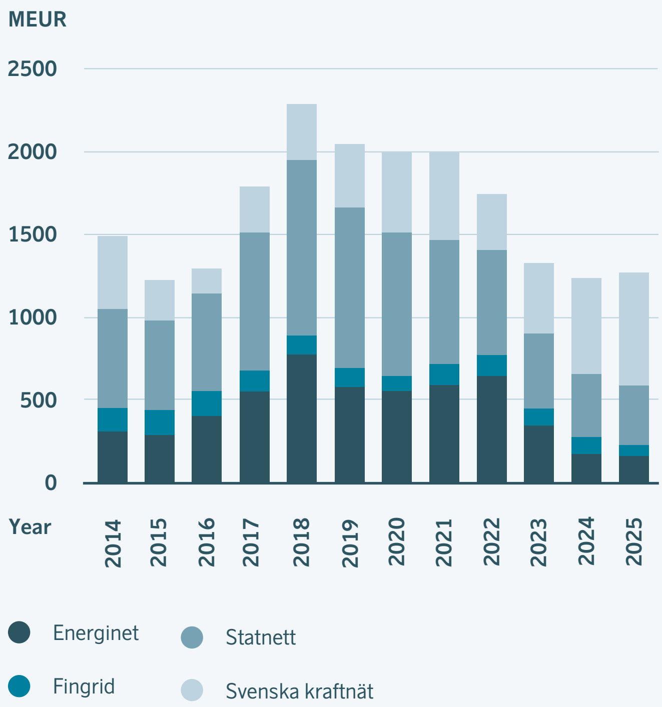


Table 2. Major cross border projects in the Nordic Grid Development Plan

Project(s)	Main drivers	Maturity
Estlink 2, NordBalt Skagerrak 4	Market integration	Commissioned
NordLink, North Sea Link, Cobra	Market integration	Under construction
Kriegers Flak	Renewables integration	Under construction
North-South reinforcements in Norway, Sweden, Finland	Renewables integration, Nuclear decommissioning, New consumption	Under construction/ Planning Analysis
Viking Link, Hansa Power Bridge DK West –Germany	Market integration	Analysis
Third AC-line Sweden-Finland	Market integration, System adequacy	Planning
Fennoskan 1 reinvestment	Market integration, System adequacy	Analysis

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Grid development – planning with a regional focus in a European context

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4.2 Future grid development

The Nordic TSOs have identified five main long-term drivers necessitating future Nordic grid investments. They relate to both the current trends in the European power markets and to the specific characteristics of the Nordic region.

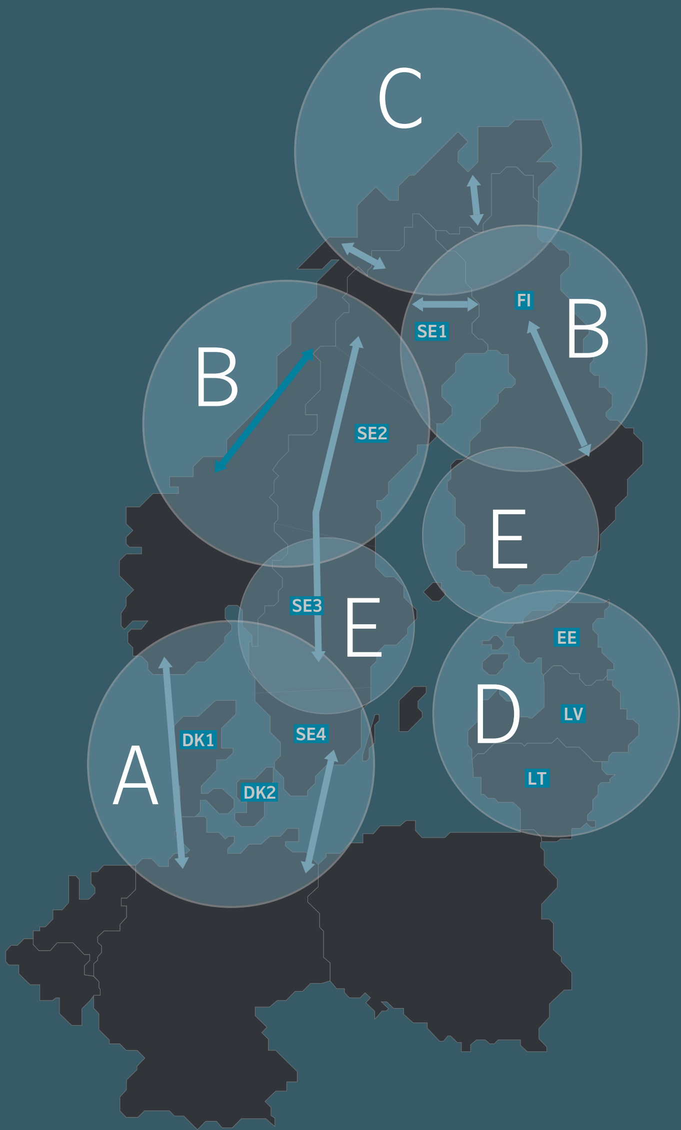
A. Further integration between Nordic countries and the Continental Europe/UK

The annual generation surplus is likely to increase in the Nordic power system (even if nuclear is decommissioned), which makes it beneficial to strengthen the capacity between the Nordic countries and Continental Europe/UK. This increases market integration as well as it furthers the value creation of renewables. In addition, it is beneficial to further connect the Nordic hydro-based system to the thermal-based Continental and wind-based Danish system, for balancing purposes, especially when large amounts of renewables are connected to Continental Europe.

B. Integration of renewables

Based on the political goals of reduced CO_2-emissions and on the decreased cost of wind and solar, further integration of renewables is expected in the Nordic countries. Both the renewables and the integration towards other synchronous systems lead to a need for increased north-south capacity.

Figure 9. Focus areas for grid development in the Nordic region



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Grid development – planning with a regional focus in a European context

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C. New consumption

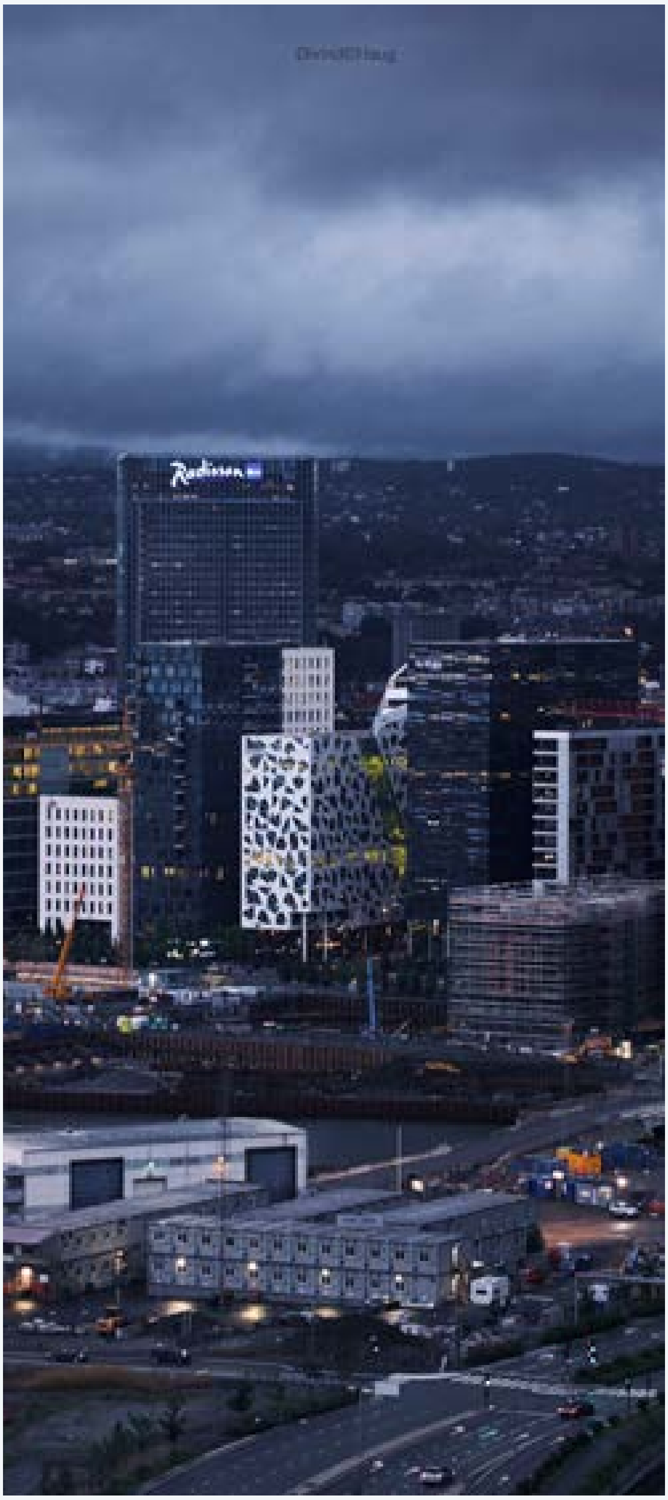
New consumption patterns are also expected to drive the need for new grid investments. In the far north, the establishment of new power intensive industries such as mines, and the shift from fossil fuel to electricity in the petroleum industry, could create a need for substantial reinforcements. The general trend with electrification of transportation, consumption increase in the larger cities etc. also puts focus on security of supply.

D. Baltic integration

To improve energy security, the Baltics aim to de-synchronize from the Russian power system. Based on an agreement between the involved Baltic Energy Market Interconnection Plan Member States, synchronization with the Continental system is the preferred alternative. The Baltic-Continental synchronization will lead to a potential increased north-south-flow (Sweden/Finland-Baltic-Poland), which has to be further investigated.

E. Future for the thermal and nuclear power

A substantial proportion of nuclear power plants, especially in Sweden but also in Finland, are expected to be decommissioned in the 2030 – 2040 horizon. This would lead to an increased system adequacy risk. In Finland, new nuclear power plants might keep the nuclear production in Finland on the pre-decommissioning level. However, it will require grid investments, as new plants are planned in other locations than existing plants. Nuclear power has many important features in today's system, and a phase out would probably require new generation capacity, grid development, as well as further development of system services.



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Grid development – planning with a regional focus in a European context

4.3 Solutions for an efficient future grid development

The future grid development is based on three principles - each of them being important solutions for an efficient future grid development:

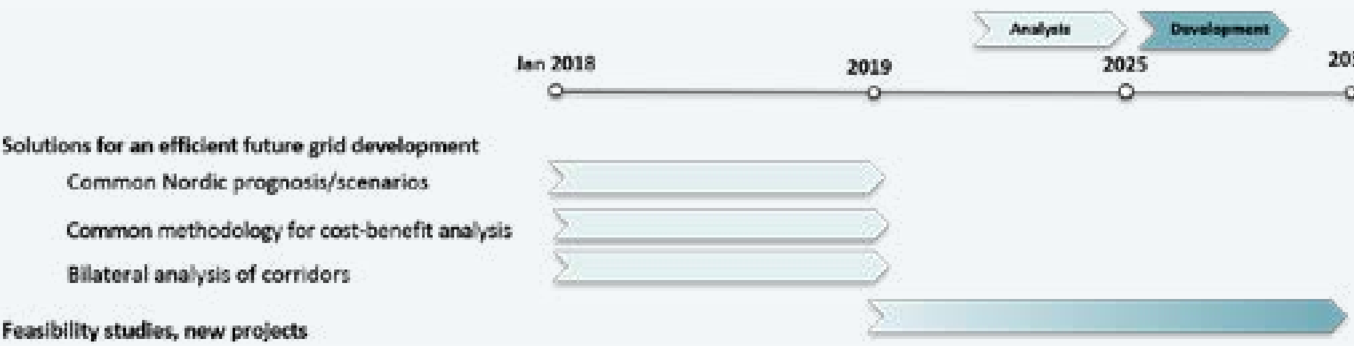
Based on the European scenarios (Ten Year Network Development Plan 2018), the Nordic TSOs will qualify **Common prognosis/ scenarios**, especially taking into account the view of the Nordic TSOs.

Common methodology for cost-benefit analysis: Based on the European methodology, which has been adopted by the European regulation, the Nordic TSOs will make agreements on how to implement the cost-benefit analysis methodology into the Nordic planning process.

Bilateral analysis of corridors: Based on the identified drivers, the Nordic TSOs see a need for further analysis of cross-border corridors in the Nordic system, potentially resulting in new projects. The corridors to be analyzed are: Norway-Denmark, Norway-Sweden (NO1-SE3), Norway-Finland, Sweden-Finland (SE1 and SE2) and Sweden-Denmark. The intention is to present the results from these analyses in the Nordic Grid Development Plan 2019.

Figure 10. Bilateral analysis of corridors

Roadmap for the grid solution



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The way forward

5.1 A more common regional framework is a prerequisite for efficient solutions

A regional approach for developing the regulatory framework is needed in addition to European regulation, to ensure that policies and measures are efficient, coherent, complementary and sufficiently ambitious. It should also be noted that common and standardized ICT solutions only make sense if the market design and rules are harmonized.

The Nordic TSOs commonly acknowledge three areas where a regional focus is particularly important:

1. The TSOs are analyzing potential long-term solutions for achieving more flexibility, but the realization of this potential depends on the incentives for market participants to provide the flexibility. These incentives are created by well-functioning energy-only power markets, where the prices reflect the value of electricity at all times.

2. A common framework for renewable energy subsidies; a harmonization of efforts and schemes will ensure that the regional system perspective is taken into account.

3. A common framework would be useful in the allocation of transmission capacity for balancing and reserve markets. This should be based on market solutions within a regional context.

5.2 Integration of digital solutions requires a focus on cyber security

To make use of the opportunities that digitalization provide, the Nordic TSOs commit to facilitating a further application and development of new technologies by providing access to data, adjusting market rules and empowering consumers.

ENTSO-E will play an important role in regards to access to Big Data on a pan-European level. It is important that Member States and the European Commission support the definition and implementation of common data exchange format and standards that ensure interoperability between all stakeholders.

5

The way forward

The drawback of digitalization and Big Data is the issue of Cyber Security. New market solutions will require high security standards, which entails high costs. An important solution in this regard is to create and implement security standards on Cyber Security, including a common exchange agreement and a security plan. ENTSO-E has a task on this. On a Nordic level, the RSC office is engaged in the development of security standards, including information security, and a Nordic group coordinates cyber security on a Nordic level.

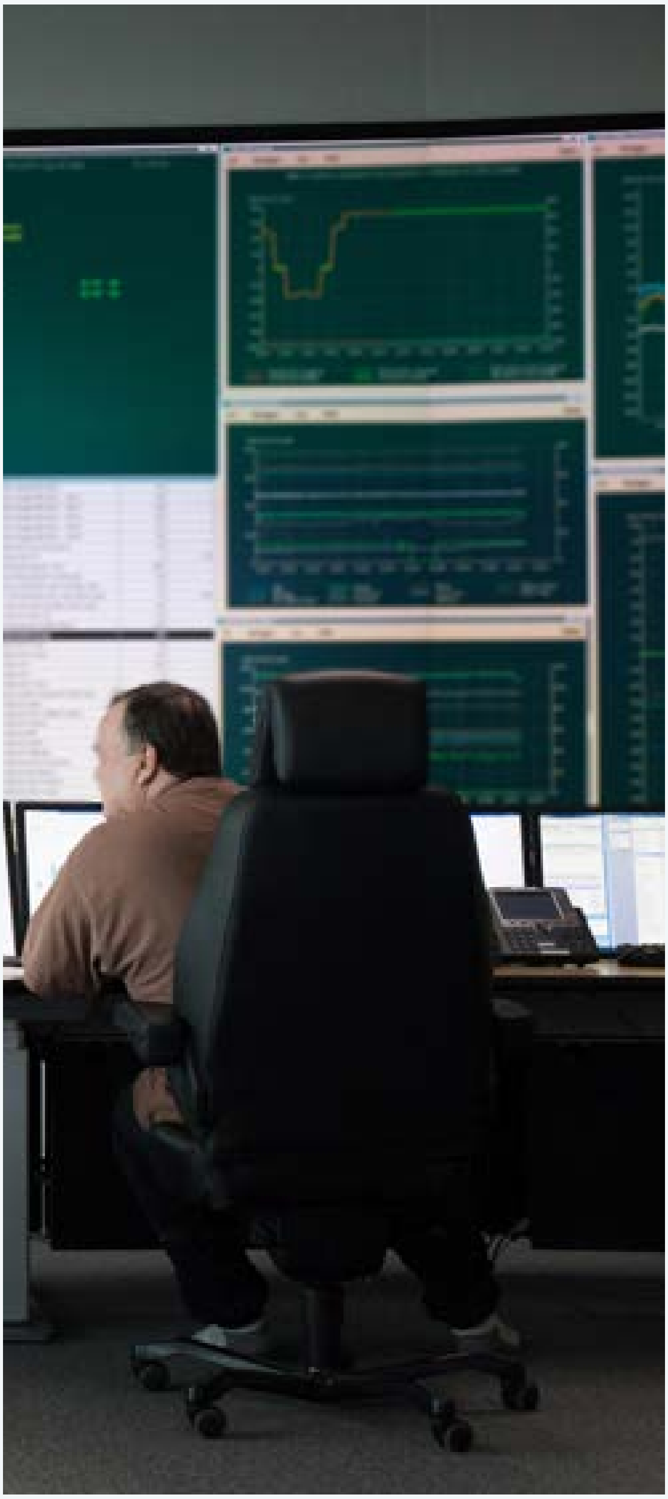
5.3 Nordic cooperation on R&D paves the way for a more automated system and future solutions

R&D is needed to address the current and future challenges for the Nordic and European power system and to pave the way for future solutions. In addition, a good innovation strategy increases efficiency and identifies cost-effective and safe solutions. Currently the Nordic TSOs have 14 on-going joint R&D projects.

Nordic R&D is very closely linked to the overall agenda of digitalization, Big Data and general IT innovation. Several of the IT tools the TSOs develop will improve internal processes but will be of little significance for the outside world. There are, however, two projects worth highlighting which aims to generate solutions to the challenge of maintainting a good frequency quality to ensure operational security, which is of high relevance for all stakeholders.

1.SPARC – SynchorPhasor-based Automatic Real-time Control – is a joint knowledge-building project between the Nordic TSOs driven by Sintef Energi and sponsored by the Research Council of Norway. The primary objective of the project is to develop new knowledge, methods and tools for automatic control and protection of transmission systems based on synchrophasor data. The methods and tools will help the Nordic TSOs improve stability and robustness to contingencies, and by this contribute to future stable and secure operation of the Nordic power system with an increased share of renewables and HVDC interconnections.

2.IMPALA is a joint project between Statnett and Svenska kraftnät where the purpose is to deliver a system that can forecast the imbalances in real-time with the help of artificial intelligence and large quantities of data, making it easier to proactively handle future imbal-



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The way forward

ances. The imbalances are foreseen to be reduced by 25 per cent and will hence reduce the frequency deviations significantly.

An appropriate funding scheme for R&D projects – NordGrid – where the Nordic TSOs are in lead, has been established in dialogue with Nordic Energy Research under the Nordic Council of Ministries. This funding scheme aims to improve the chances of overcoming innovation barriers, by motivating co-operation between TSOs, universities, R&D and industrial partners.

The R&D organizations of the Nordic TSOs (Nordic R&D group) are establishing a roadmap for Nordic R&D. The purpose is to tackle the challenges addressed in the report "Challenges and opportunities for the Nordic Power System" since many solutions are knowledge related – more insight is needed to evaluate the solutions.

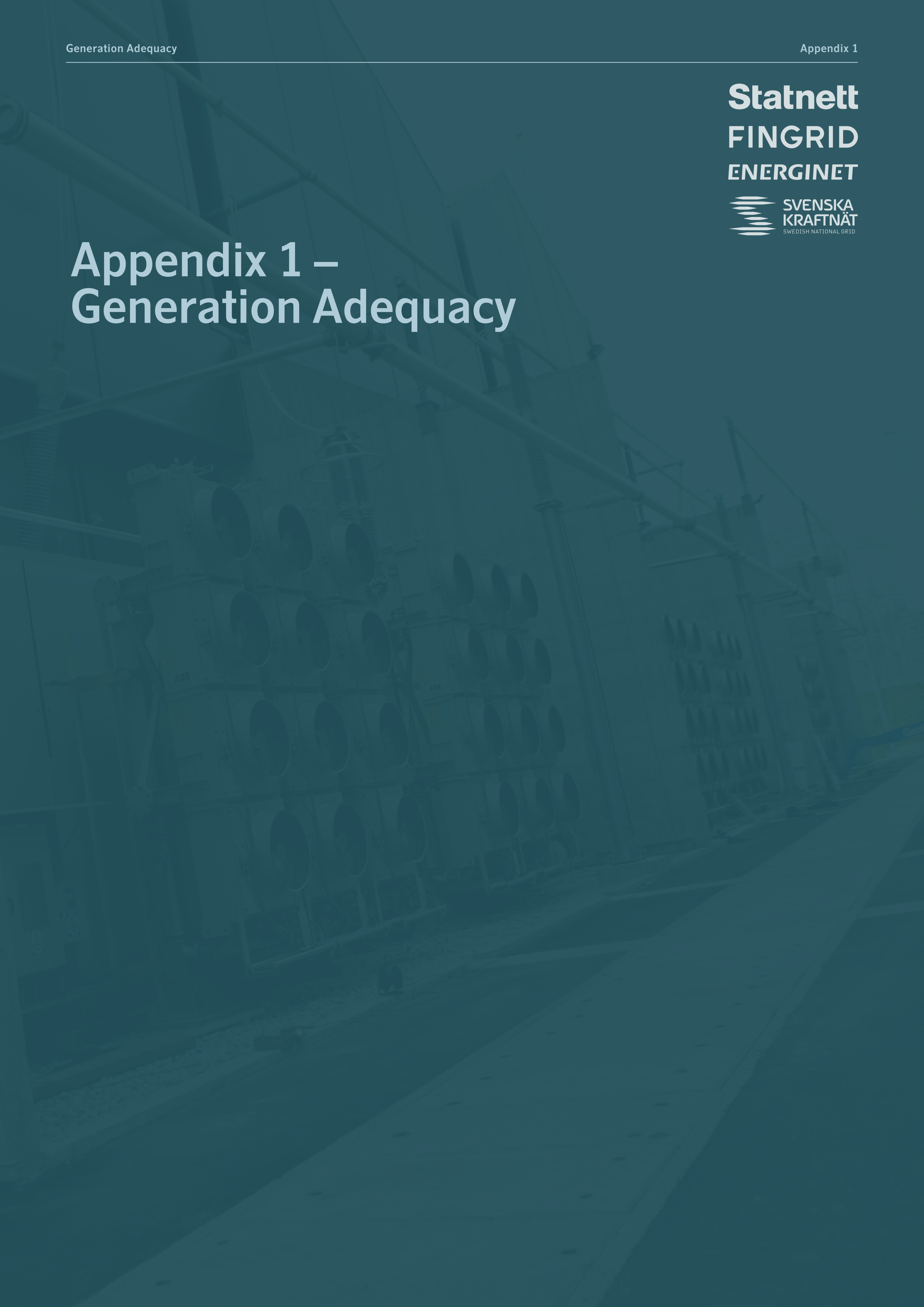
5.4 The Nordic TSO "way forward" – in a nutshell

IT development is paving the way forward; while a variety of common Nordic projects are framing the road with support stations and traffic signals. In the best of all worlds, the road just needs to be filled with producers, consumers and prosumers eager to contribute and benefit from a well-functioning Nordic power system.

In reality, however, much more needs to be done on the policy and regulatory side in order to ensure effective cooperation across the Nordic region. Preparing the Nordic power system to cope with the challenges ahead can only be secured in combining efforts on all three cooperation levels; energy policy, common system solutions and dedicated solutions.

This report is the first of its kind to present a system wide overview of the solutions the Nordic TSOs are working on in order to meet the future challenges for the Nordic power system. The Nordic TSOs' intention with this report is to support the cooperation on energy policy and to provide our stakeholders with a transparent insight to the Nordic TSOs' projects and activities - the report hence aims to increase transparency and enhance dialog between TSOs and our stakeholders.

The intention is to up-date this publication every second year and organize stakeholder events to discuss the progress. Up-dated roadmaps will be provided for these events. In addition, stakeholder engagement on dedicated solutions will continue, but our ambition is to lift discussions to a more Nordic (regional) level.



Appendix 1 – Generation Adequacy

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Generation Adequacy

Introduction

Power markets are at a crossroad. The structure of power generation capacity is changing towards more intermittent renewable energy, less base load generation and fewer flexible power plants. The rising share of wind power leads to increased variability in power production. As a result, low prices and market uncertainties are influencing the profitability of conventional generation, which has accelerated the retirement of conventional thermal and nuclear power plants, and increased the risks of investing in new capacity. The changes are seen across Europe, which has brought the concern regarding generation adequacy and the ability of a power market to supply this, back on the agenda.

The supply-demand balance is influenced by the shift in the generation mix, and several studies state that the risk of capacity shortage is increasing at national levels and for certain time periods. The Nordic area as a whole, however, is expected to have a significant energy surplus on an annual basis.

A well-functioning power market is a key enabler to solve the so called trilemma of a cost-efficient transition to a low-carbon power system that still provides a high level of security of supply and competitive prices to businesses and citizens. For this, the European Commission launched a winter package of measures called "Clean Energy for All Europeans". Some of the principles for the variety of measures are increased flexibility of generation and load, scarcity pricing, and increased coordination across borders. The overall ambition is that future power markets will be able to send clearer price signals to producers, consumers and investors. Additionally, there needs to be enough transmission capacity to form prices in large enough areas.

Well-functioning markets ensure generation adequacy

In essence, generation adequacy is about ensuring that supply meets demand or vice versa. To enable this in a market-based solution, it is of vital importance that prices hold all relevant information on the tightness of the balance between supply and demand. This will incentivise producers to regulate production and consumers to adjust demand. In scarcity situations, the price must increase above the variable generation cost, thereby incentivising investments in new generation capacity. Long-term price levels need to enable recovery of investment costs for flexible production. Thus, securing adequate capacity is first and foremost a question of getting prices right.

However, many decisions and incentives affect the generation capacity and the consumption patterns in the Nordic power market. Several of these are defined outside the area of responsibility of the TSOs, for example subsidy schemes for renewable energy, energy taxes, environmental regulation, industrial policy etc. Thus, an increased coordination on policy measures between the Nordic countries, especially for those that have an effect on the common Nordic market, would be beneficial. This should also include the creation of common Nordic design principles for strategic reserves, if needed in the future.

In addition, adequacy assessments need to be on a regional basis in order to include cross-border capacity in the evaluation. Here methods developed for Pan-European adequacy assessment can provide the basis if adjusted for Nordic risks and supplemented with specific Nordic sensitivity analyses. This approach is currently employed for the first Nordic generation adequacy report to be published in Q3 2017.

Elements in getting prices right to support generation adequacy

The power market model needs to be updated to ensure that it delivers a continuous high level of generation adequacy. The Nordic TSOs have identified several areas within the current market model that should be developed further, in order to accommodate the changes in the power system in a marked-based and efficient way. The suggestions for market measures have a time span of the next five years and consist of the following:

- Ensure that market prices are allowed to guide investments in generation capacity.
- Ensure that the value of generation adequacy is duly incorporated into analyses of the economic benefit of transmission grid investments internally, between the Nordic countries and to the neighbouring regions.
- Internalize the risk of shortage in the market prices, especially in the balancing market, to enable flexible consumers and producers to capitalize on their flexibility in realtime.
- Linking wholesale and retail markets closer together in order to ensure that consumers receive the price signals in time to respond.

Generation Adequacy

- Conduct pilot projects to promote demand response and examine possible market concepts for aggregators.
- Increase use of market-based solutions for ancillary services where possible in order to let the market know what the TSOs need.

The Nordic TSOs have already investigated and started a substantial amount of initiatives in order to "get the prices right" and improve our knowledge for decision making. Specifically, the TSOs are working on four concrete projects that will contribute to solve the adequacy challenge:

- **Higher time resolution in the power markets:** Introducing higher time resolution in the power markets will reduce the magnitude of structural imbalances, which in turn frees up reserves and improves the frequency quality in the Nordic power system.
- **Full cost of balancing:** Improving the incentives for balancing responsible parties to be in balance by exposing them to the true cost of imbalances. This will also contribute to the adequacy situation by improving market rules to bring more flexibility.
- **Common Nordic capacity calculation methodology:** Adopting a common capacity calculation methodology in the Nordic region will maximize the welfare created from the utilization of the grid, which will be important also for tackling the regional adequacy challenges.
- **Empowering consumers:** Enabling consumers to benefit from potential flexibility in their demand by utilizing smart technology and developing new services and products in retail, wholesale and balancing markets.

A critical element of realizing the full potential of Demand Side Response (DSR) could be the facilitation of the aggregator role that allows third parties to aggregate multiple loads and offer these as additional flexibility to the market. The Nordic TSOs have recently completed a project aimed at developing guidelines for 3rd party aggregation in the balancing markets in the Nordic countries. The project has investigated which market conditions and aggregation models that are most suitable for the Nordic countries, and identified barriers and opportunities for old and new market players. In addition, several national pilot projects in the four Nordic countries focus on increasing demand side response and facilitate aggregation.

Adequate transmission capacity supports supply-demand balance

Transmission capacity plays a key role in meeting the generation adequacy challenge by enabling cost-effective utilization of generation resources. Increased transmission capacity between the Nordic countries and continental Europe allows for export of power surplus as well as import in situations of scarcity. The same applies to transmission capacity within the Nordic countries. The Nordic countries are strongly interconnected, but further reinforcements are planned and foreseen to be needed in the future. The status of planned and potential interconnector projects is reported in the Nordic Grid Development Plan 2017.

In this context, it should also be noted that transmission capacity alone cannot ensure generation adequacy in the Nordic market. Investment in generation capacity as well as realization of the potential for flexible demand is key to ensure the supply-demand balance.

Intervene only if markets fail to deliver

If the above mentioned measures are not sufficient for the energy-only market to ensure a balance between demand and supply, or initiatives are needed to bridge the gap in a transitional period, then strategic reserves are preferred as market wide capacity mechanisms.

Today, two Nordic countries – Sweden and Finland – have strategic reserve mechanisms to ensure balance between supply and demand in extreme situations. Generating units are kept available for occasions when the market is not able to cover demand. Both power plants and loads may serve as peak load reserve. Power plants and loads that act as peak load reserve are fully reserved for the use of the peak load reserve system, hence they cannot participate in the commercial market.

Strategic reserves should be designed so that their interference with market price formation is as small as possible. The Nordic TSOs therefore recommend that future strategic reserves should:

- be designed to address the nature of the problem identified in adequacy assessments at the European or regional level,
- be regional if capacity or demand can contribute across borders, though bearing in mind that establishing a common Nordic strategic reserve is complex and requires thorough analysis.
- not interfere with price signals in the markets.

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Generation Adequacy

This is in line with suggestions in the winter package "Clean energy for all Europeans", where capacity mechanisms, including strategic reserves, are seen as a last resort, i.e. if the markets after removal of potential regulatory distortions cannot ensure a desired supply-demand balance. The suggested rules on capacity mechanisms will complement existing state aid guidelines by creating a European framework and concrete rules for cross-border participation.

To ensure a valid regional assessment of the necessity of strategic reserves, it is essential to monitor the demand-supply balance very closely, before suggesting measures concerning a possible regional strategic reserve.

Improved methodology for Nordic adequacy assessments

The Nordic TSOs are developing a common platform for assessing long-term generation adequacy. This centres on identifying and quantifying the risks to the future delivery of power to consumers. To this end, a probabilistic approach is employed, which captures the uncertainty related to variable generation, plant and interconnector outages, and the effect of weather conditions on demand. This is an improvement over the deterministic approach, which only considers worst-case scenarios by comparing peak load with average availabilities on generation and transmission facilities. The deterministic approach fails to capture the many different combinations of events that could lead to adequacy issues. The probabilistic approach therefore gives a better understanding of how the different elements of the power system contribute to generation adequacy.

The assessment is conducted using the market model BID[1] and builds on ENTSO-E's annual Mid-Term Adequacy Forecast, which models all of ENTSO-E, including the Baltics and Turkey, and corresponds closely to actual price areas. Flows across the perimeter (for example to and from Russia) are modelled as fixed flows based on historical data. To give a relevant regional focus, specific sensitivity analyses of Nordic interest are conducted.

The methodology takes its point of departure in the normal operating scenario including all market measures such as exchange on interconnectors and demand responses. The risks associated with operation of the power system in times of stress and the mitigation measures here used, are hence not included in the evaluation.

The first step in determining the risks to generation adequacy is to construct a large number of possible future states based on the uncertainty surrounding the demand for power, and the availability of power plants and interconnectors. Each future state is established on the basis of historical data. The key inputs for generating future possible states are:

- Wind and photovoltaic production
- Outdoor temperatures (which result in load variations)
- Hydro conditions (normal, wet or dry years)
- Scheduled and unscheduled outages of power plants and interconnectors

The climatic variables are correlated by nature. Therefore, the climatic data relating to a given variable for a specific year is combined with data from the same climate year for all other variables. Through this process, different distinct climate years are constructed with demand and intermittent energy production specified for each hour of the year. In contrast, the availabilities of power plants and interconnectors are randomly selected considering given probability parameters (this only relates to unscheduled outages, scheduled outages are fixed throughout the year). A future state is produced by combining a climate year with a randomly generated availability profile. **Figure 1** illustrates this Monte Carlo method[2].

Construction of Monte Carlo Years

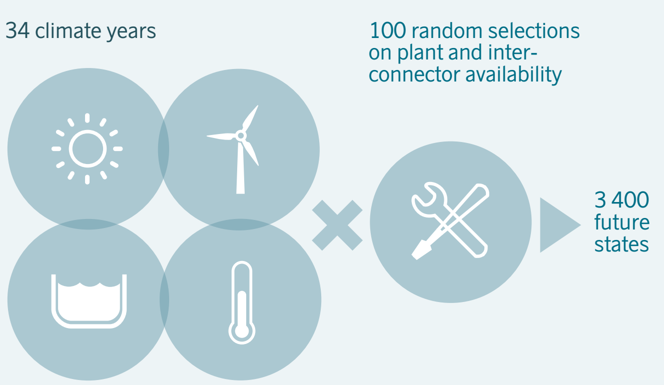

Figure 1: Illustration of the construction of future states (graphics created by Elia, Belgian Transmission System Operator).

1 Better Investment Decisions (developed by Pöyry Management Consulting).
2 Graphical illustrations created by Elia, Belgian Transmission System Operator.

Generation Adequacy

By combining each climate year (34 in the latest Pan European Market Model Database) with 100 different random selections on plant and interconnector availability, 3 400 future possible states are produced.

The second step involves identifying periods of structural shortage, i.e. times when there is insufficient available power to meet demand. This occurs when multiple events coincide, such as low wind during a winter day with a fault on a large power plant. To this end, an hourly simulation is carried out where the model optimises the distribution of interconnector capacity in order to maximise the minimum regional capacity margin. This is done for all hours in all 3 400 future states. Averages across these years will give the expected state of the system.

The last step is to quantify risks through different indicators, and illustrate how much capacity is needed to mitigate the risks. This level can not be interpreted as a requirement for strategic reserves, as none of the Nordic countries has set a risk target for security of supply. Furthermore, the periods with the most significant imbalances need to be analysed in detail in order to understand the cause, as well as assess whether model weaknesses may cause over- or under-estimation of loss of load.

The most commonly used risk indicators are loss of load expected (LOLE) and expected energy not served (EENS). LOLE is the expected number of hours per year in which generation adequacy problems occur. It is not the expected number of hours in which consumers may be disconnected, as both short-term and long-term mitigation measures are available to the TSOs. EENS is the amount of demanded power in MWh that cannot be met in a given year. EENS therefore combines both the likelihood and the potential size of any supply shortfalls. The third indicator used is the Capacity Margin, which is the capacity or demand response in MW needed for obtaining balance in each hour.

In addition to the above described basic application of the probability based generation adequacy assessment method, the joint Nordic Generation adequacy study is investigating the effects of the following situations, which may pose a threat to the demand and supply balance in the Nordic region:

- Extreme weather conditions
- Closure of thermal capacity (nuclear and CHP)
- Lasting grid constraints
- Import capacity from Russia

Two other sensitivities of interest which are being investigated are:

- New HVDC lines (as suggested in the TYNDP18)
- Location of future wind production

Conclusions

The common basis for the Nordic TSOs is that the market design must create a framework for market-based solutions, which can pave the way for the demand-supply balance. This is in line with the ambition of the winter package from the European Commission.

The Nordic TSO's work on generation adequacy relies on energy-only markets with higher time resolution, where the market is the main driver for ensuring generation adequacy. This clarifies the role of the TSOs somewhat, as generators and consumers decide on investments and consumption based on market signals, while the TSOs support the development of an efficient market framework and sufficient transmission capacity.

The Nordic TSOs have already made changes and adjustments, or are in the process of implementing them. In several of the areas in question, new legislation and political decisions may be needed, or agreement will have to be reached among the Nordic countries or in the EU.

One of the prerequisites for finding the right measures is however, the correct assessment of generation adequacy on a national and regional scale. This will be ensured through the application of a probability based modelling tool with input data used for ENTSO-E's annual Mid Term Adequacy Forecast, supplemented with specific Nordic sensitivity analyses. First results of this consistent Nordic assessment will be available Q3 2017.

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Appendix 2 – Nordic Grid Development Plan 2017

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Content

1 Introduction

The Nordic council of ministers tasked in December 2016 the Nordic TSO's with presenting a Nordic Grid Development Plan 2017. This Nordic Grid Development Plan describes the ongoing and future investments in the Nordic grid. The main focus of the development plan is to communicate the status of individual projects and identify corridors for further analysis.

Transmission capacity plays a key role in addressing the future challenges of the power system. Adequate transmission capacity allows for cost-effective utilization of power, ensures access to generation capacity, enables exchanging system services, and is the key for a well-integrated market. Strong transmission networks are a prerequisite for a cost-efficient transition towards a green power system.

A large amount of new renewable generation is expected to be built, especially in the northern parts of Sweden and Finland. This will significantly increase the north-south flows in the Nordic transmission grid. Both existing and potential new transmission lines will transmit the energy surplus in the north to the consumption centres in the south. In addition to new lines inside the Nordic countries, planned new interconnectors will strengthen the integration of power markets towards Continental Europe and UK.

The Nordic Grid Development Plan 2017 describes drivers for further development of the Nordic power system. Based on the drivers presented as well as internal studies, the Nordic TSOs see a need for further investigations of several cross-border corridors in the Nordic system (Norway-Denmark, Norway-Sweden, Norway-Finland, Sweden-Finland, Sweden-Denmark). The intention is to present these investigations in the next Nordic Grid Development Plan 2019.

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The Nordic grid planning process

The Nordic cooperation regarding grid development, which previously was done within Nordel, is now primarily performed under ENTSO-E's organization. The latest ENTSO-E Regional Investment Plans were published in 2015. They listed possible future project candidates that were presented in the 2016 Ten Year Network Development Plan (TYNDP 2016). New Regional Investment plans are planned to be published late 2017.

The Nordic TSOs take an active part in the common regional planning done within ENTSO-E's regional groups Baltic Sea and North Sea, but also cooperate on grid planning issues on Nordic level. In 2014 Nordic TSOs re-established a Nordic planning group (NPG) in order to ensure continuous Nordic focus on regional transmission grid planning.

The Nordic TSOs also cooperate on creating joint scenarios used in studies of future transmission system needs. These studies are performed within ENTSO-E as well as bilaterally between Nordic TSO when further evaluating possible projects between the Nordic countries.

The final decision on which projects to realise is taken by each TSO and presented in the national grid development plans. The cooperation on scenarios and joint planning issues ensures that there is a consistency between the projects presented in the national plans and how they contribute to solve the Nordic and European grid development challenges. The common goal of the Nordic TSOs is to even further coordinate Nordic system planning activities.

The status of Nordic grid development has been reported to the Nordic council of ministers in 2012 and 2014. In 2016, focus was shifted from grid planning to system planning to also include operational and market issues. The report "Challenges and Opportunities for the Nordic Power System" reports on the issues facing the Nordic system in the future, following expected changes in production and consumption. While a lot of focus is put on these system issues and how to handle them with market and operational adaptions, grid reinforcements are still needed. The transfer capacity within and between different market areas makes the foundation for both energy trade and for an efficient use of new and existing system services. As an example, since the last report Svenska kraftnät and Fingrid have jointly decided to start implementation work on the third AC line that has been studied for a long time. The line will increase trading capacity and the possibility to exchange system services as well as increase the power adequacy in Finland.

3

Regional drivers for grid development

The European power system is undergoing a fundamental change in how electricity is generated and used as well as on a political level. Conventional thermal power generation is being phased out and replaced with intermittent renewal power production with different technical characteristics but also at new locations. Electricity is also replacing fossil fuels in many areas of use and has an even more vital role in today's society than ever before. On the political level, there is a strong will to form a more closely coupled European Energy Union. These changes cause many challenges and opportunities for the Nordic power system and their impact on Nordic grid development is presented as a number of drivers, or focus areas, for the Baltic Sea region that all have an impact on the Nordic countries.

Focus area A: Further integration between the Nordic countries and the Continent/UK

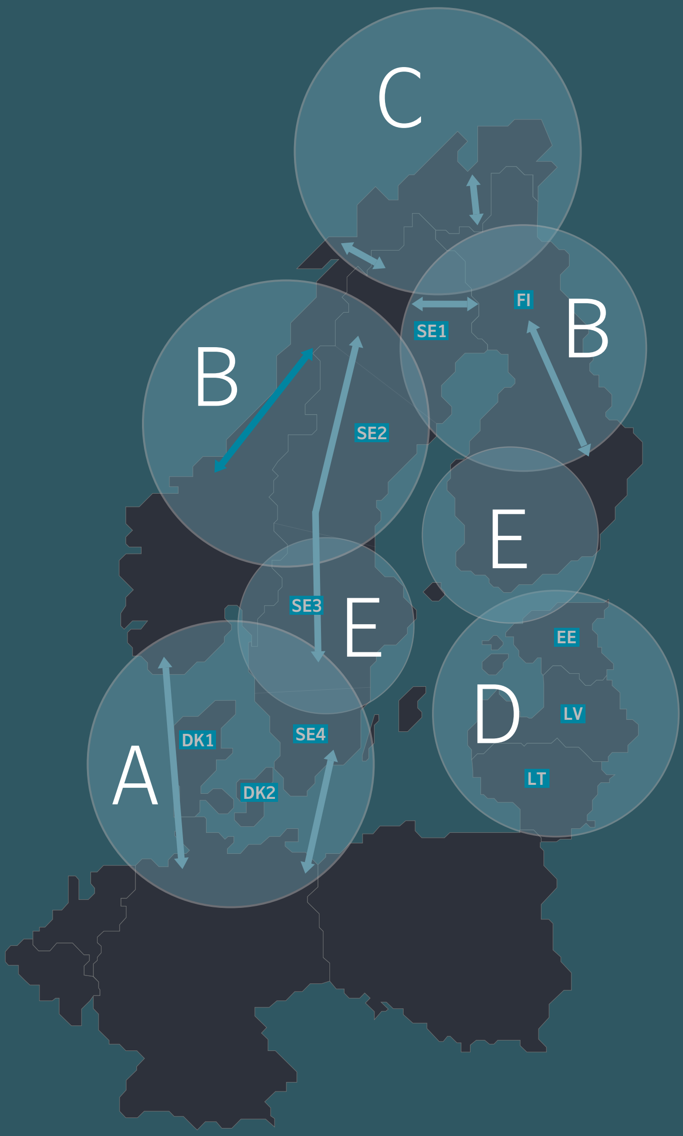
The Nordic system is likely to increase the annual energy surplus (even if some nuclear is decommissioned), which makes it beneficial to strengthen the capacity between the Nordic countries and UK/Continental Europe. This increases market integration as well as it increases the value creation of renewables. In addition, for daily regulation purposes, it will be beneficial to further connect the Nordic hydro-based system to the thermally based continental and wind based Danish system, especially when large amounts of renewables are connected to the continental system.

Focus area B: Integration of renewables and North south flows

Based on the political goals of reduced CO_2-emissions and based on the cost development of wind and solar, further integration of renewables is expected in the Nordic countries.

New interconnectors to the continent/UK/Baltic States in combination with substantial amounts of new renewable generation capacity is increasing the need to strengthen the transmission capacities in the north-south direction in Sweden, Norway, Finland and Denmark. In addition, nuclear and thermal plants are expected to be decommissioned in both southern Sweden and Finland which further increases the demand for capacity in the north-south direction.

Map of focus areas



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Regional drivers for grid development

Focus area C: New consumption

Depending on location and size, new electrical consumption may also trigger the need for grid investments. In the far north, the establishment of new power intensive industries such as mines, or the shift from fossil fuel to electricity in the petroleum industry, could create a need for substantial reinforcements. The general trend with electrical transportation, consumption increase in the larger cities etc. will also put focus on how to secure the supply.

Focus area D: Baltic integration

Based on energy security the Baltic States aim to de-synchronize from the Russian system. Based on an agreement between the involved BEMIP-Member States, synchronization with the Continental system is the preferred alternative for the Baltic system. The Baltic-Continental synchronization and other market based changes will lead to a potential change in the north-south-flow (Sweden/Finland-Baltic-Poland) which will have to be further investigated.

Focus area E: Future for the thermal and nuclear power

A substantial proportion of thermal and nuclear power plants, especially in Sweden but also in Finland, are expected to be decommissioned in the 2030 horizon. This would lead to an increased system adequacy risk. In Finland, Olkiluoto 3 will be taken into operation before any older nuclear plant is decommissioned and Fennovoima is planning to build a new NPP Hanhikivi 1. Realisation of the Hanhikivi 1 NPP would keep the nuclear production in Finland on the pre-decommissioning level, but it will require grid investments, as it is planned to be built at a different location than existing NPP's. Nuclear power has many important features in today's system, and a phase out will require new generation capacity, grid development, and further development of system services.

3.1 Reinvestments

Additional to the grid reinforcements in response to the grid development drivers, there is also an increasing need for reinvestment in the grids in the Nordic region. A large part of the transmission grids was built during the 1950s and 1960s. Reinvesting by replacement of old lines and substations with new, often with higher capacity, has already started, but the need for reinvestment will be a long-term requirement.

4

Status of Nordic projects

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 TSO's. The investment levels are at a historically high level and are foreseen to be so also in the coming years. In total, the Nordic TSOs plan to invest more than €15 billion until 2025.

4.2 Previous Nordic reinforcements

The Nordic TSO:s have in the last ten years through common planning increased the internal Nordic transmission capacity substantially by taking into operation a number of new internal reinforcements. Among them are Nea - Järpströmmen (2009), Great – Belt (2010), Fenno-Skan 2 (2014) and Skagerrak 4 (2014). These have been reported on in more detail in earlier Nordic grid plans.

4.3 Status of projects in the Nordic area

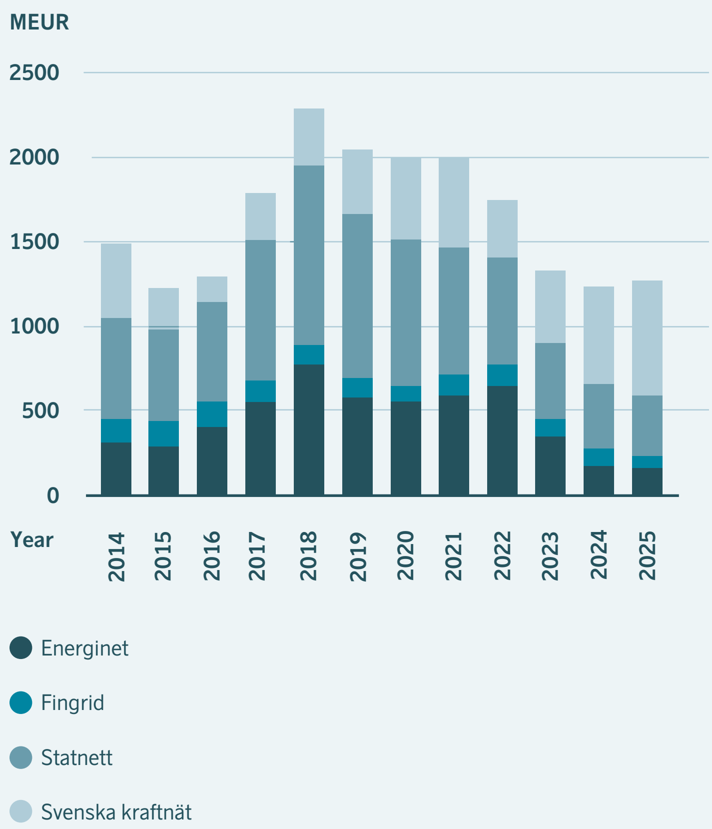
The status of different projects in the Nordic area are reported in this section as:

- "Taken into operation", meaning that the project has been taken into operation since the reporting of status in the Nordic Grid Development Plan 2014
- "Under construction/Decided", meaning that a final investment decision has been taken and the projects 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 have started

In the reporting the projects have been categorised as: *National projects of Nordic importance, Cross border projects within the Nordic Area, Interconnectors to other synchronous areas*

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 2016-17 and a new application procedure for the period of 2018-19 has just started. A reference is also given to whether a current PCI-project has re-applied or not.

Total investments by the Nordic TSOs



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Status of Nordic projects

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 to use the cross border interconnectors efficiently. The most important internal investments are listed below.

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Finland

The 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 the national supply while the projects in Southern Finland are important for local security of supply and internal capacity availability for full utilization of HVDC connections.

	Project	Status	Description
F1	**Hikiä-Forssa**	Taken into operation 2016	New 400 kV AC single circuit OHL of 78 km between substations Hikiä and Forssa.
F2	**North-South reinforcements stage 1**	Taken into operation 2014-2016	New 400 kV AC single circuit OHLs of 111 km between substations Ulvila-Kristinestad, 212 km between substations Hirvisuo-Jylkkä-Pyhänselkä. New series compensation in Hirvisuo. Projects allowed to connect new wind power generation and increased transmission capacity in P1 cross section with ~700 MW.
F3	**Lieto-Forssa**	Under construction Expected in operation 2018	New 400 kV AC single circuit OHL of 67 km between substations Lieto and Forssa.
F4	**Hikiä-Orimattila**	Under construction Expected in operation 2019	New 400 kV AC single circuit OHL of 70 km between substations Hikiä and Orimattila.
F5	**North-South reinforcements P1 stage 2**	Planned/Under consideration Seeking permission 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.
F6	**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. Project will deliver 800 MW increased in transmission capacity.

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Finland

	Project	Status	Description
F7	**Fennovoima NPP connection**	Planned/Under consideration Seeking permission Expected in operation 2024	This project involves a new double circuit 400 kV OHL line between Valkeus (FI) and Lumimetsä (FI). The new line is required for connecting Fennovoimas new nuclear power plant planned to be built in Pyhäjoki. The power plant has a planned generation capacity of 1 200 MW. The decision to build the connection and schedule depends on when the construction permit is given to build the Hanhikivi NPP.
	Olkiluoto 4 connection	Taken out of grid development plan	TVO did not apply for Olkiluoto 4 construction permit. The principle license to build a nuclear plant is expired.

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Norway

The 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 at the same time secure an adequate SoS-level.

	Project	Status	Description
N1	**Voltage upgrades through north and mid of Norway**	Several projects Under construction In operation	Will potentially increase the capacity in the north-south-direction. Detailed information given in Statnett's Grid Development Plan 2017.
N2	**Ørskog–Sogndal**	Taken into operation 2016	New 420 kV-line (ca.300 km) will increase capacity north-south-direction and towards mid Norway. The project will increase the security of supply in mid Norway as well as facilitate RES.
N3	**Fosen**	Under construction Expected in operation 2019	New 420 kV-lines in mid Norway (Fosen) in order to facilitate new wind production. Detailed information given in Statnett's Grid Development Plan 2017
N4	**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 (ca.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–Varanger-botn) is under consideration, however no decisions taken.
N5	**Western corridor**	Under construction Final step expected in operation 2021	Voltage upgrades in the Southwestern part of Norway. The project will increase the north-south capacity as well as facilitate high utilization of the planned interconnectors. Detailed information given in Statnett's Grid Development Plan 2017

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Sweden

The 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. Due to the rather low energy prices it is not uncommon for connections of renewable production to be put on hold by the applicant prior to final implementation.

	Project	Status	Description
S1	**SouthWest Link**	Under construction Expected in operation 2017/18	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 Nord-Balt and the planned Hansa PowerBridge with less risk for limitations. The project has been delayed several times due to difficulties in the implementation phase.
S2	**Ekhyddan – Nybro - Hemsjö**	Planned/Under consideration Seeking permission Expected in operation 2023	This is currently a PCI-project and has re-applied 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 utilize the NordBalt interconnection that is connected in Nybro.
S3	**North-South SE2 – SE3**	Planned/Under consideration Expected in operation 2017 and beyond	New shunt compensation and upgrades of existing series compensation between price areas SE2 and SE3 are planned for installation between 2017 and 2025. The oldest of the 400 kV lines between SE2 and SE3 are expected to be replaced with new 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.
S4	**Skogssäter - Stenkullen** **Swedish west coast**	Planned/Under consideration Seeking permission Expected in operation 2021	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.

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Denmark

The 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 summarized in the table.

	Project	Status	Description
DK1	**Endrup-Idomland** **Revsing-Landelupgaard** **Idomland- Tjele** **Bjæverskov-Hovegaard**	Planned /Under consideration 2019-21	All projects are 400 kV domestic transmission lines. The purpose of the investments is to integrate on-going and planned connections of renewable generation (off-shore wind farms) and to connect new interconnectors (COBRA, Viking Link, DK West-Germany etc., see section 4.3.3) to the domestic grid.

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4.3.2

Cross border projects within the Nordic areas

	Project	Status	Description
CB1	**3rd AC** Sweden - Finland	Planned/Under consideration Seeking permission Expected in operation 2025	The project has applied for PCI-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.

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4.3.3
Interconnectors to continental Europe/Great Britain

	Project	Status	Description
CB2	**NordBalt** 700 MW Sweden – Lithuania	Taken into operation 2016	HVDC subsea interconnection between Sweden and Lithuania that has increased the trading capacity between the Baltic States and the Nordic electricity markets.
CB3	**Kriegers Flak CGS** 400 MW Denmark East - Germany	Under construction Expected in operation 2018	Secure connections to shore are vital for the Kriegers Flak offshore wind farm. Together with German TSO 50Hertz Transmission GmbH an offshore interconnector is being developed. 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. The European Commission is supporting the interconnection with up to 150 m€.
CB4	**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 Q1 2019.
CB5	**NordLink** 1400 MW Norway – Germany	Under construction Expected in operation 2020	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/Continental Europe in periods with negative power balance (low wind, high demand etc.). In addition, 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-emission.
CB6	**NSN Link** 1400 MW Norway – Great Britain	Under construction Expected in operation 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 Great Britain in periods with negative power balance (low wind, high demand etc.). In addition, 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-emission.

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4.3.3

Interconnectors to continental Europe/Great Britain

	Project	Status	Description
CB7	**Denmark West - Germany**	Under construction and Planned/Under consideration (Consenting) Expected in operation 2020 and 2022	On the Denmark West and Germany border there are two projects. The east coast project which is an upgrade of the 220kV lines from Kassø to Jardelund to 400kV, increasing the capacity on the border to 2500MW 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 400kV line from Endrup to Nibüll where it is to connect with the 2 400kV 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 2500MW to 3500MW in 2022.
CB8	**Viking Link** 1400 MW Denmark West – Great Britain	Planned/Under consideration Consenting Expected in operation 2022	The Viking Link project is under development with the Danish §4 application sent to the ministry in December 2015. The project aims at integrating the electricity markets of GB and DK to increase the value of wind power as well as improving security of supply in GB 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.
CB9	**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.
CB10	**NorthConnect** 1400 MW Norway-Scotland	Under consideration	A 650 km long subsea interconnector between western Norway (Sima) and eastern Scotland (Peterhead). According to Statnett's Grid Development Plan 2017, a second Norway-UK-interconnector might show positive cost/benefits.

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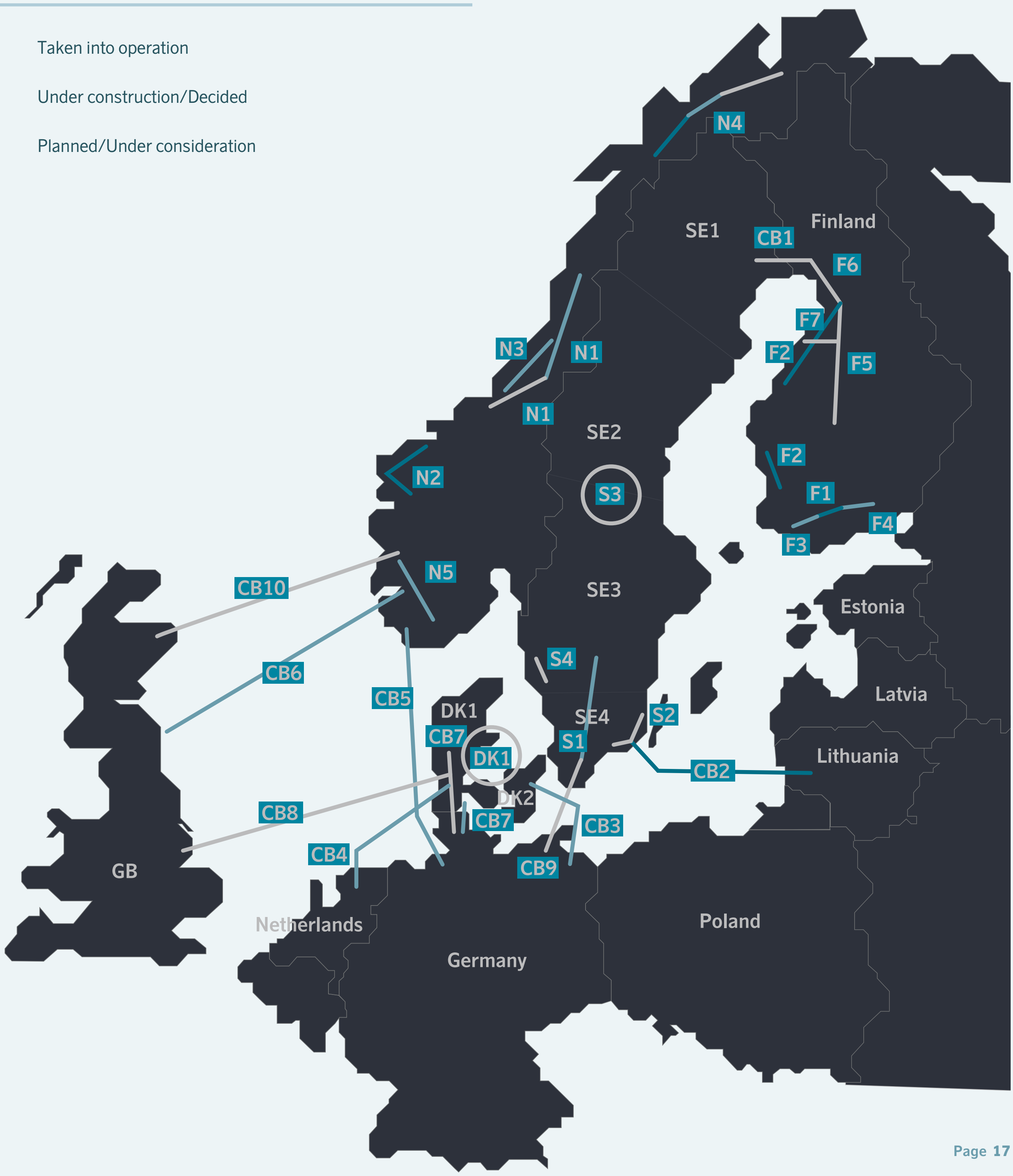
Map of projects

4.4 Map of projects

- Taken into operation
- Under construction/Decided
- Planned/Under consideration



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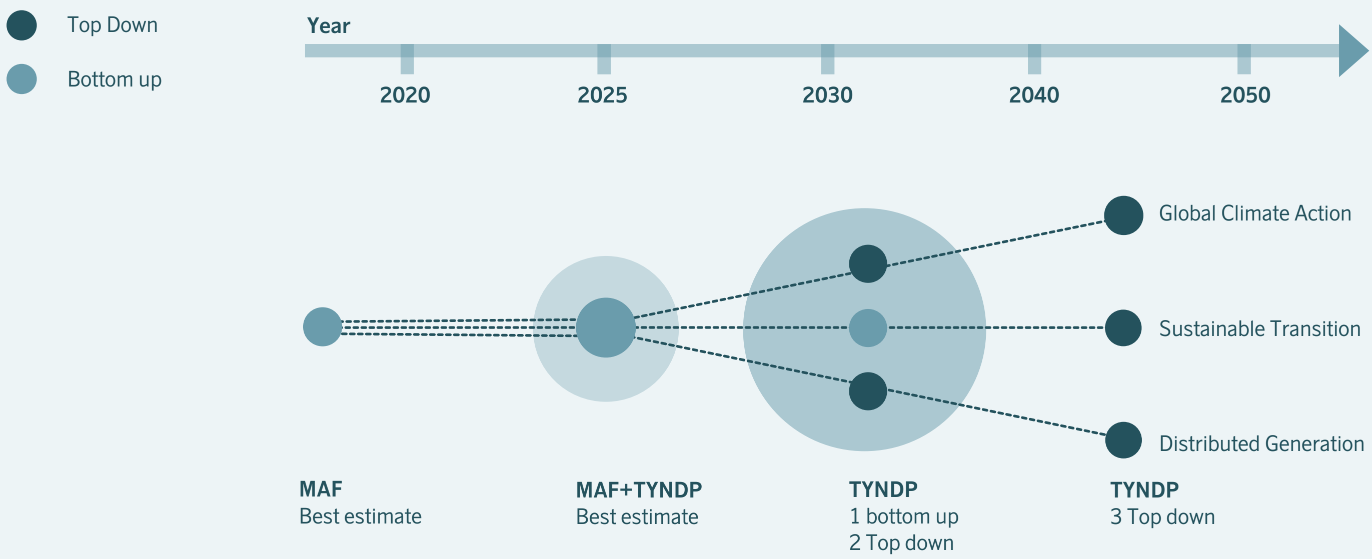
Scenarios for the future

There are several ways to identify a need for increased capacity between two market areas. One is obviously to take note of the price differences seen in the market and if the difference is too large on an average, there is probably a need for reinforcement. However, the future energy system will change, but it is not clear how, and some changes might have a big influence on the market, the power flows and the need for future capacity. These are the reasons why grid development is done using scenarios to predict the future. Since many parameters that affect the electricity market are unknown, several scenarios and sensitivities are used to evaluate how robust an investment is.

5.1 European scenarios for TYNDP 2018

In the work with ENTSO-E´s regional investment plan 2017 and the TYNDP 2018, scenarios for 2025, 2030 and 2040 have been created. There is one scenario for 2025 based on all TSOs best estimate (a so-called bottom-up scenario). From 2025, three different development routes are assumed to create different scenarios for 2030. One scenario is based on the TSO's best-estimate (bottom-up) while two scenarios are created using levels of renewable production and other parameters defined in a top-down approach by ENTSO-E centrally to fulfil different European political goals. For 2040, three more scenarios are created, all of them top down decided scenarios fulfilling all political targets.

Scenario framework



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Scenarios for the future

Scenario year	Scenario name	Description
2025	Sustainable transition "Best estimate"	Development based on currently known plans. More reliable than the long-term scenarios, but still not a forecast.
2030 and 2040	Sustainable transition	A moderate expansion of wind and solar, partly supported by direct subsidies. EU on track with 2030 climate targets, but not quite reaching the targets for 2050.
2030-2040	Distributed generation	Significant leaps in innovation of small-scale generation and storage is a key driver. High expansion of wind power and very high expansion of solar panels. Many residential prosumers.
2030	European target	Based on a scenario developed for the EU Commission. The scenario is quite similar to Global climate action.
2040	Global climate action	A global emission trading scheme (ETS) is a key driver towards meeting both 2030 and 2050 climate goals. The global ETS prevents carbon leakage between countries, and therefore improving the relative competitiveness of energy intensive industries within Europe.

5

Scenarios for the future

The Nordic input for the European bottom-up scenarios is coordinated by the Nordic TSOs, and is based on each TSOs Best Guess for 2020, 2025 and 2030. Hence, these scenarios might be seen as a common Nordic prognosis. Towards the Nordic Grid Development Plan 2019 these scenarios/prognosis will be further developed.

5.2 Common Nordic scenarios

The Nordic TSOs have commonly created, together with the TSOs in the Baltic States, best estimate scenarios for both 2025 and 2030. They are based on the following main assumptions and trends.

- The European Emission trading system (ETS) is not considered the main driver of decarbonisation in the electricity production sector. This means that coal should be cheaper than gas for power production, however coal as fuel is assumed to be phased out due to national regulations.
- Increased production from wind, solar and hydro (especially in Norway) is assumed due to higher national subsidies, decreased costs for wind and solar production and higher hydro-inflow.
- Nuclear plants are assumed to be decommissioned according to the communicated official plans (Ringhals 1, 2 and Oskarshamn 1) and or by reaching the expected technical lifetime (Loviisa 1 and 2). Rest of the nuclear capacity is expected to still be economically viable in 2030. In Finland two new reactors is commissioned before 2030 (Olkiluoto 3 and Fennovoima1).
- Demand is assumed to grow slowly due to energy efficiency measures. Both Denmark and Norway expect the largest relative growth as a result of electrification in the transport sector as well as from increased industrial demand.
- The slow growth in demand and continued increase in renewable generation will yield a substantial Nordic energy surplus even after some nuclear de-commissioning.

These best estimate scenarios have been used in calculations done in the ENTSO-E Regional investment plans that will be presented in 2017. In order to check for robustness in the results a number of sensitivities, adjustments of single parameters or assumptions, have been applied. The most important ones are:

- Reduced nuclear: Nuclear plants could be decommissioned earlier than expected due to several reasons. The effects of this need to be analysed.
- Low-price: Low prices in combination with continued subsidies could cause low profitability for conventional generation which would therefore be de-commissioned faster. This would lead to an even more volatile system with less schedulable generation capacity.

The Nordic TSOs will continue to jointly develop scenarios to be used in the evaluation of possible reinforcement needs in future Nordic Grid Development Plans.

6 Identified corridors of further interest

In the last ten years a number of new interconnector projects have been commissioned or are under construction between the Nordic countries towards continental Europe and the Baltic States. The status of these projects are described in chapter 4.

The regional drivers described in chapter 3, as well as analysis done by the Nordic TSOs indicate that it is now important to look in more detail on internal Nordic transmission corridors. Sufficient internal capacities are an important factor to utilise the full benefit from the already decided new interconnectors and to assure the function of the Nordic power market. It is also important to make it possible to meet future demands for even more trading capacity between the Nordic countries and surrounding areas in order to accommodate higher levels of renewable power. Such studies will be reported within the scope of the Nordic Grid Development Plan 2019 as well as in the Regional investment plan 2019 and the TYNDP 2020.

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.

6

Identified corridors of further interest

Norway – Denmark

One of the drivers for investigating future investment needs for the Norway-Denmark corridor is the expected technical lifetime of Skagerrak 1 and 2 which were commissioned in 1977, thus a decision on the future of these lines will have to be taken over the next few years. In addition, further integration between the Nordic synchronous and the Continental synchronous system may be needed in order to provide the flexibility needed for the expected generation-shift.

Norway – Sweden

A possible decommissioning of Swedish nuclear power plants would be the main driver for investigating the Norway-Sweden corridor (NO1-SE3). If decommissioning, increased capacity towards the southern part of Sweden might be needed for an adequate security of supply.

Norway – Finland

The drivers for investigating the Norway-Finland corridor are the possible changes in the Arctic region with both Norwegian petroleum-activities which might increase the consumption as well as very good wind potential that would give a large surplus that needs to be transported out of the area.

Finland – Sweden

The main driver for further investigation of future investment needs is the ageing of Fenno-Skan 1 HVDC link between SE3 and FI and its importance for the trade between Sweden and Finland. The link could be replaced at the current location or moved to a new location between SE2 and FI.

Denmark – Sweden

The corridor between Denmark and Sweden is of interest to investigate since it links areas with hydro power (Sweden and Norway) with areas with high dependencies on wind and solar power. The oldest HVDC link from Denmark west to Sweden, Konti-Skan 2 from 1988, is approaching its technical lifetime and may have to be replaced within the next 15-20 years.

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