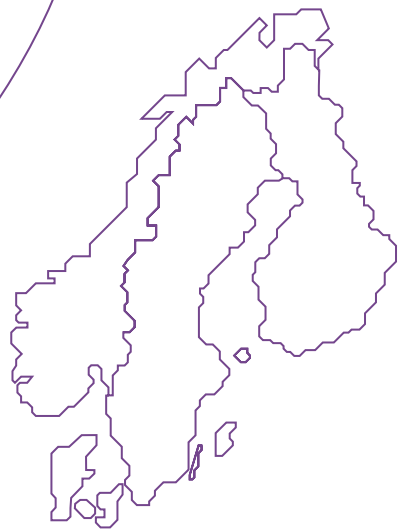
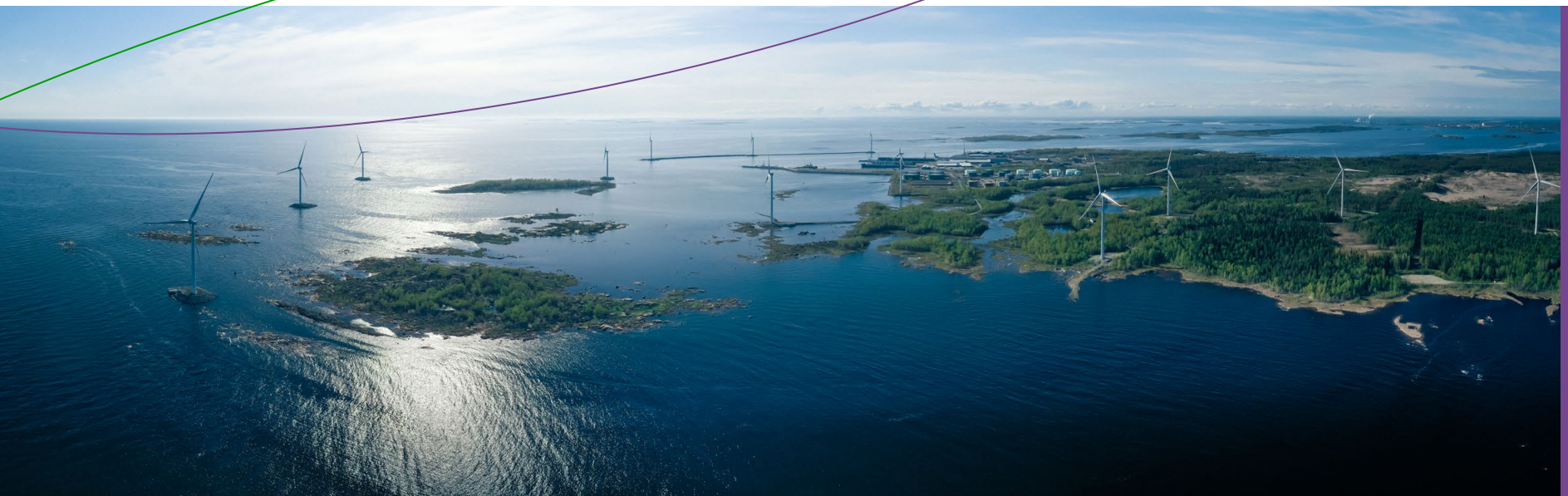
2022

SOLUTIONS FOR A GREEN NORDIC ENERGY SYSTEM

Strategies to meet the climate challenge





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CONTENT

SUMMARY

The energy sector is in transition towards a net-zero-system. The main drivers are climate change and the pursuit of sustainable growth. Together with political top-down efforts like COP 26, EUs Green Deal and Fit for 55 policies, the bottom-up efforts of customers for green electrification are gaining momentum. This means that the Nordic electricity transmission system operators (TSOs) are facing a growing demand for grid capacity and grid connections to meet the huge need for more clean electricity towards 2030 and beyond.

Electrification based on weather-dependent clean energy sources is a major climate solution. The challenges of the Nordic electricity system relate to power balance, generation adequacy and grid capacity as well as how to get more system flexibility. Also, the decrease in inertia and frequency quality in the power system need to be addressed.

The Nordic TSOs' report "Solutions for a green Nordic energy system – Strategies to meet the climate challenge" aims to address the challenges and describes the work on solutions and presents the Nordic TSO strategy towards 2030 focusing on wind development and sector integration. The strategy looks at the areas where the TSOs need to take measures, and furthermore, where common action by the Nordic TSOs is required.

In 2016, the four Nordic TSOs presented a report describing the challenges to the Nordic power system following from the transition towards a more sustainable energy system. This was followed by reports in 2018 and 2020 focusing on the solutions to the challenges facing the common Nordic power system. Together the TSOs have embarked on a wide range of joint development projects that will gradually introduce a number of new solutions that will add to the resilience of the Nordic system.

The ongoing work includes profound changes to the Nordic balancing model and the related markets for reserves, including the introduction of a 15-minute imbalance settlement period and the change of markets into 15-minute market time-unit. Furthermore, system operations will be improved by the introduction of a Nordic Regional Coordination Centre (RCC) to provide a more efficient power system on a Nordic level. These innovations will bring about better and more automated power system operations but will also provide more accurate price signals to the markets.

The TSOs now see that long-term transmission system planning will face more complexity by taking into account other sectors that use electricity, such as the transport, heating and hydrogen production sectors. In total the Nordic TSOs are planning to invest more than EUR 25 billion in the coming decade. These efforts will reduce bottlenecks in the power system and enable electrification and the integration of large amounts of new renewable generation, primarily wind power, both off- and onshore.

In 2020, a new page was turned when the Nordic TSOs decided to develop a joint strategy covering two key topics: Wind power and sector integration towards 2030. The strategy is based around four key elements that weave it together like a “green thread”: **electrification** is the key to mitigate climate change, but it will require increased generation, mainly from renewable and variable **wind power**. Its variability will require more **flexibility** from all available sources. Furthermore, **sector integration** will enable us to optimise the clean energy system across several energy infrastructures.

The Nordic strategy is based on the vision of a Nordic region that has excellent conditions for wind power, advanced electricity markets with easy market access and good co-operation among all stakeholders. This will provide a trustworthy basis for green investments while also maintaining a stable and reliable electricity system.

The vision of the Nordic TSO strategy is to have clean and competitive electricity that enables a climate-neutral, secure and integrated energy system.

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In total the Nordic TSOs are planning to invest more than EUR 25 billion in the coming decade.

In selecting the means necessary to reach these goals, three particular areas of action will need to be addressed.

Firstly, adequate infrastructure is needed. The adequate infrastructure will include both the Baltic and North Sea regions. At the same time, we need to speed up connection to the grid. We also need to get the most out of the existing infrastructure, which implies an optimal utilisation and performance of the existing system. When developing the infrastructure to meet the needs from the customers, we have to make sure to use the full transmission technology mix for further grid expansion.

Secondly, providing a secure system and integrated markets. Market access and financial incentives for all energy resources to provide adequacy, flexibility and ancillary services needs to be ensured. We have to develop the requirements for new energy resources to ensure their flexibility and system security. Also, tools to monitor flexibility and to forecast it at a Nordic level are needed. To respond to the growing amounts of offshore wind, we need to introduce offshore bidding zones and integrate offshore solutions in the electricity market.

Thirdly, optimise energy infrastructure. We need to develop tools and create cooperation models for holistic energy system planning and use ambitious wind power and electrification scenarios in system planning.

The development of the four Nordic TSOs' common strategy is only one step in the direction of fulfilling the vision of enabling clean and competitive electricity that enables a climate-neutral, secure and integrated energy system. The strategy towards 2030 has now been formulated, but it has to be implemented for the vision to come true. Therefore, an implementation plan designating specific measures for the Nordic TSO cooperation for the next years has been agreed.

The strategy has identified six key success factors:

1. Broad cooperation across all energy sectors and stakeholders is vital
2. Nordic TSOs must develop and maintain adequate infrastructure for effective markets and renewable energy sources
3. All sources of flexibility – in consumption, energy storage and generation – are needed for balancing and congestion management
4. Easy and equal market access and proper incentives for all energy resources are required provide adequacy, flexibility and system services
5. Power system planning, including the Baltic and North Sea regions, must consider all energy sectors and types of infrastructure to enable optimisation of the entire energy system
6. There needs to be streamlined processes to make the grid capacity and grid connections available in time

2 INTRODUCTION

Energy at the core

Although progress was not as far-reaching and unanimous as hoped for, the United Nations Climate Change Conference (COP26) in Glasgow confirmed and reinforced the international efforts for a green transition.

Energy is at the core of a "net zero society" and the Nordic Transmission System Operators (TSOs) are fully committed to contribute to the green transition that is needed to fulfil future visions. In 2016, the Nordic TSOs published a comprehensive study describing the wide range of challenges that lie ahead of the Nordic countries as we move towards a sustainable energy system. The study was followed up by reports in 2018 and 2020 called "Solutions", which laid out the framework for how to achieve our common goals. This current report takes stock of where we are right now, and where our concerted efforts are taking us. However, the report also reiterates and reinforces the common strategy we must adopt towards 2030 in order to attain zero emissions by 2050, highlighting two main areas of interest: The rapid expansion and integration of wind power, both offshore and onshore, and furthering sector integration in the Nordic countries.

The Nordic countries have a good starting point for transformation. We have the skills, the resources and the traditions required to foster the green transition and support sustainable growth. Also, the Nordic TSOs are well placed to enable electrification in order to facilitate the green change. As we uphold a steady supply of power, we will pave the way for an array of new investments and business opportunities, such as flexibility services. Together with stakeholders, the Nordic TSOs want to explore new solutions that could prove beneficial not only to the energy system, but also to businesses.

The green transition is happening as we speak. The Paris Agreement in 2015 was a call for global action. The European Union responded with the European Green Deal, which was legally confirmed with the European Climate Law – and more recently the Fit For 55 programme, which is the road map that will take Europe to net zero by 2050. With COP26,

the 1.5 degree target is confirmed and validated. Thus, global emissions must be halved by 2030, halved again by 2040 and eliminated by 2050.

However, equally important to the top-down political force for change is the response from business and citizens. In recent years we have seen a formidable increase in the demand for electrification. The green transition is also growing very fast bottom-up. More actors want more clean power. Together with a technologically informed citizenry, it portrays a Nordic region that is ready for a green future.

These are all good signs and an indication that the energy transition is "getting up to speed". At the same time, it crystallises the challenges to the future energy system.

Need to balance the system and the market

First and foremost, resilient system operations are becoming more challenging day by day. Increasing volatility in power production and flows between regions challenge system operations and lead to increased price variations.

The way the green transition is achieved is key to maintaining public confidence. The development of an adequate and responsive energy system, as described in this report, would arguably make a significant contribution to safeguarding a sustainable path towards society's future goals. However, it serves to emphasise a crucial part of the future energy strategy: The need for flexibility. For the system to deliver, the gap between demand and supply has to be filled at all times. In an energy system that runs on decarbonised and renewable sources and responds to a continuous drive towards electrification, larger fluctuations will be the norm – and the energy system has to respond with versatility in order to maintain resilience.

The Nordic countries are well equipped with green natural resources from waterways and wind, both offshore and onshore, but the exploitation of these vast resources needs to be efficient and holistic, from both market and infrastructural points of view. We need to apply a cross-sectoral perspective on energy infrastructure. The price mechanism provides us with a "universal language" whose message should be heard and heeded across the different energy markets, enabling us to optimise a wider energy system, and not only the electrical system. Price variations incentivise consumers to develop and utilise a wide range of flexibility options with different characteristics, regarding both response times and the duration of response. The development and digitalisation of these flexible responses are essential for balancing the future power system, and for the efficient utilisation of more variable renewable power generation.

Furthermore, the expansion of grid and generation capacity must move in steps. In order to simultaneously secure grid access and system efficiency, as well as to avoid stranded assets, we need to coordinate and balance the development of system and market. Better cooperation between demand and supply should contribute to shorter lead times and reduced uncertainty, thereby fostering profitable and timely investment projects. Actors working together across sectors, interests and roles is a prerequisite for nurturing a balanced and efficient approach.

> **The digitalisation of flexible responses is essential for balancing the future power system with more variable renewable power generation.**

Hence, stakeholder participation and collaboration with other parties have been paramount in the process leading up to this strategy. Through several webinars we have attempted to bring together different voices from energy and industry. A concerted effort across sectors is the only viable path to the green transition and the TSOs will continue to involve stakeholders on a broad scale as we move towards implementation of the strategy outlined in this report.

It is in the common interest of all stakeholders that the Nordic TSOs develop a resilient power system that can absorb booming electricity consumption and a growing share of intermittent energy.

Ongoing projects that support the strategy

Nordic TSOs have already started preparations for the energy transition and are engaged in large set of ongoing national, Nordic and European:

- Nordic TSOs publish a common Nordic Grid Development Perspective (NGDP) every other year to communicate a common Nordic view on the development of the future power system, the status of ongoing and planned investments of Nordic significance, and how the investments contribute to Nordic socio-economic welfare.

- The Nordic TSOs have large portfolios of ongoing and planned grid development projects. In total the Nordic TSOs plan to invest more than EUR 25 billion over the next ten years. This will reduce bottlenecks in the power system and enable the integration of large amounts of new renewable generation, primarily wind power.

- The introduction of a single price model, 15-minute imbalance settlement period and 15-minute products for day-ahead, intraday and balancing time frames, as well as common markets for the frequency restoration reserve, initially in the Nordic region but later on European platforms, will bring about better and more automated power system operations, but also provide more accurate price signals to the markets.

- System operations will be improved by the introduction of a Nordic Regional Coordination Centre (RCC) to engender a more efficient power system on a Nordic level.

- Long-term transmission system planning shifts towards joint energy system planning by taking into account other sectors that use electricity, such as transportation, heating and hydrogen production. Currently, the Nordic scenarios for electricity demand form the basis of long-term system planning.

- The first stage of flexibility markets has been started with ongoing pilots to introduce additional flexibility to the energy system.

The roadmap for the ongoing projects is presented on page 10.

Nordic challenges have to be met

Clean electricity is bound to play a key role in the energy transition. The four TSOs see a need to adopt a common approach to ensure efficient integration of wind energy to our power system and to support and utilise the integration of energy sectors in order to reduce greenhouse gases. In addition to the challenges presented in previous Nordic reports, such as lack of inertia and decreasing quality of frequency, the Nordic TSOs and the entire Nordic energy sector are facing a number of challenges, among those are:

- How do we ensure that the Nordic countries are attractive for new green investments regarding supply of renewables and new types of flexible demand that may ensue from sector integration?

- How do we unlock the potential for flexible operations, providing much needed grid services, as well as optimal location of new plants through market measures, harmonisation and tariffs?

- How will the rapid build-out of renewables and the development of sector integration impact infrastructure planning when optimising the energy system across both complementary and competitive infrastructure types?

- How can the Nordic TSOs ensure adequate and available infrastructure for both existing and new actors, while taking into account the interests of societal stakeholders?

- How can the TSOs balance further market harmonisation, increased data sharing and a closer coordination of Nordic operations with the national differences in regulation, grids and energy system developments?

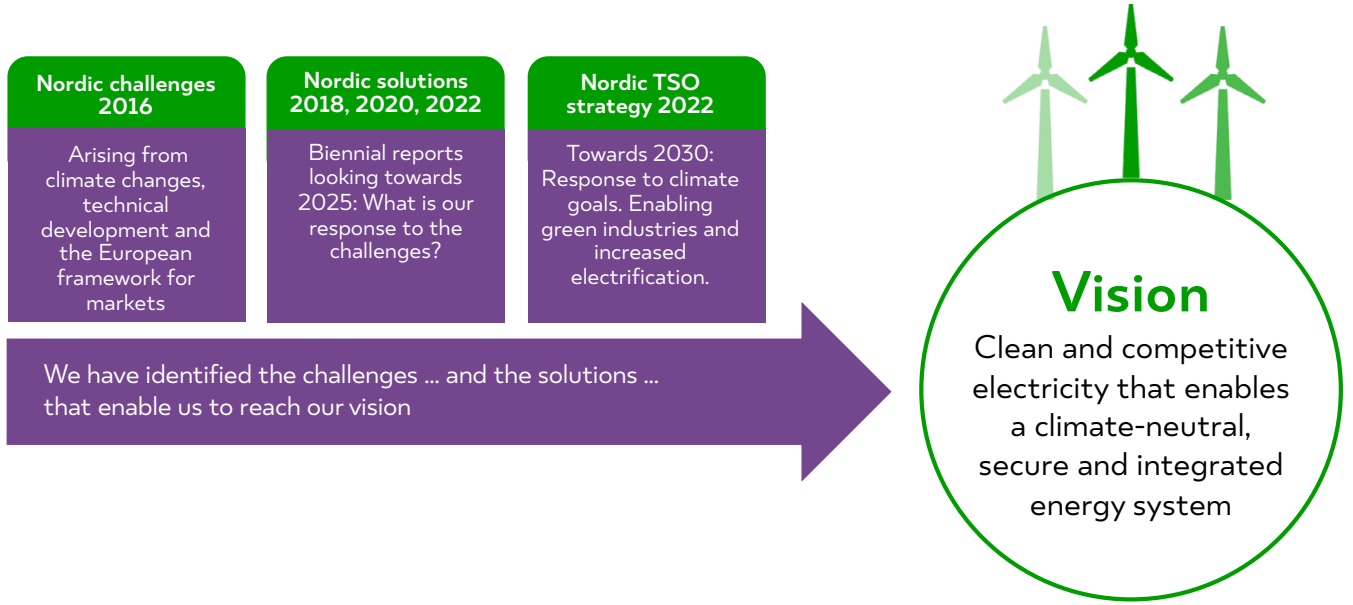
The strategy outlined in this report marks a major step forward in the joint efforts of Nordic TSOs to meet these challenges. Nevertheless, we are fully aware that in order to succeed, we will have to work even harder and intensify our common efforts in the years to come.

The TSOs have a pivotal role

The power grid connects producers and consumers of electricity and the TSOs provide access to the grid and the markets for them. While investments in clean generation and demand facilities will obviously be carried out by other actors, TSOs have a pivotal role in providing users and producers with competitive conditions, thus enabling investments and electrification.

TSOs will as such play a crucial role in paving the way for sector and wind power integration and, with the rapidly progressing energy transition, this needs to happen at an unprecedented pace, while simultaneously ensuring security of supply at all times.

In response to this, the Nordic TSOs have formulated a strategy that will guide future work. The strategy will comprise a Nordic vision and how to achieve it. It will also recognise and consider the developments and requirements taking place at the EU level and in surrounding regions such as the Baltic and North Sea regions.

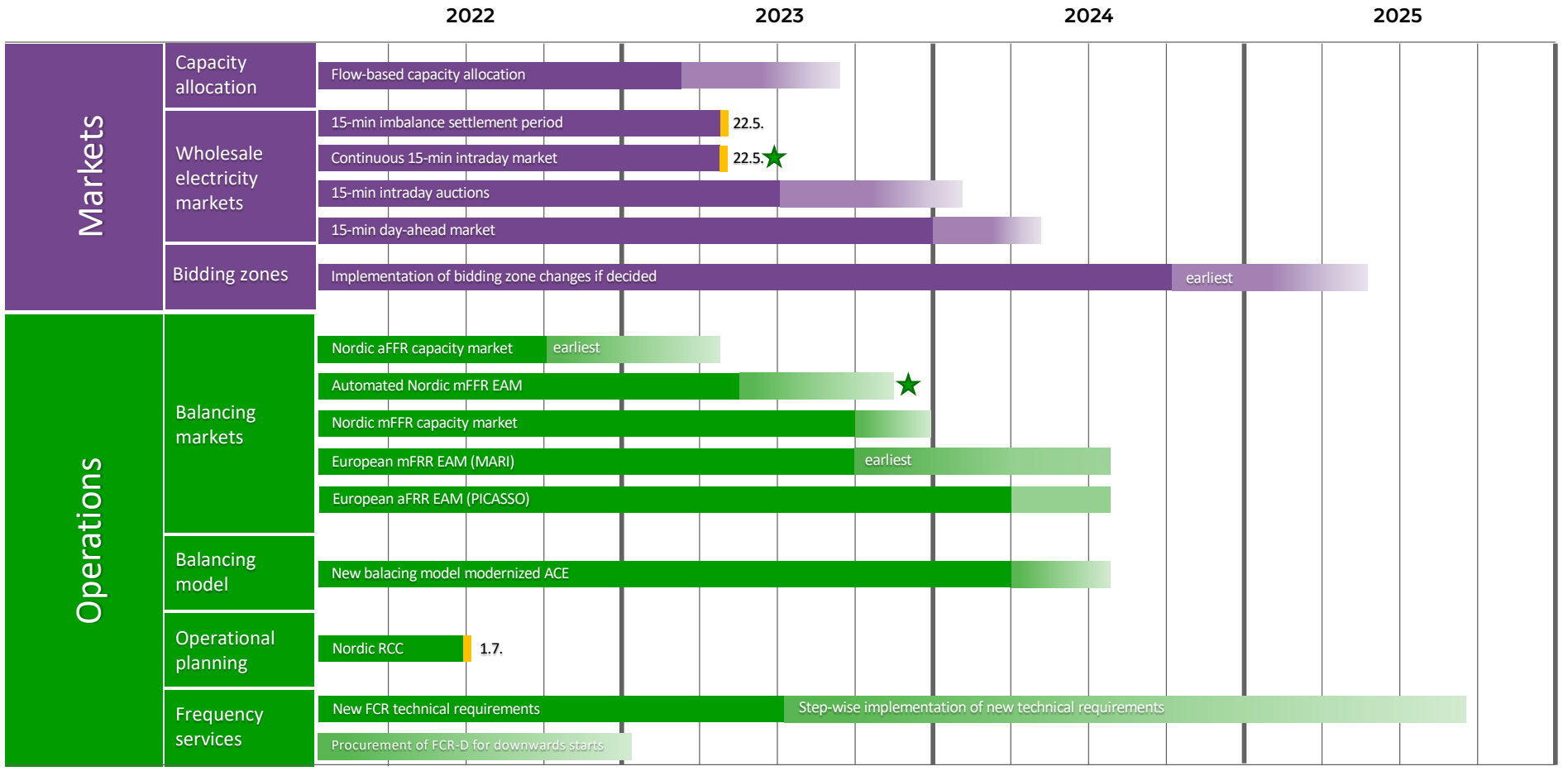


The green transition is built on a foundation of R&D, cybersecure IT infrastructure and digitalisation

From a TSO perspective, the solutions required to complete the green transition are a mix of known and unknown technologies and principles. To achieve an efficient transition, research and development (R&D) is essential, and this will not be conducted by the TSOs alone – primarily because they rarely develop technologies themselves but mostly apply and use new technology in market development and automation of system operations, for example. It is essential to cooperate closely between TSOs and stakeholders such as technology providers, universities and renewable energy developers, and even known solutions must be tuned to fit the new era. This need for research and development is relevant across all elements of this report and is therefore not mentioned explicitly for each topic. The green transition involves new ways of cooperating in the energy sector and requires a new understanding of how societies can achieve the goals for 2030 and beyond. Hence, there is also an essential role for R&D regarding societal challenges such as the acceptance of new energy solutions, sustainability, cooperation, the role of new players and, last but not least, the economic efficiency and robustness of the future energy system in order to meet societal expectations.

Apart from R&D, there are two other fundamental prerequisites for success: cybersecure IT infrastructure and digitalisation. The green transition is happening at a time when digitalisation offers a new set of tools that are ideal for managing and controlling a green electricity system with increasingly complex parameters. Thus, all systems are built with digitalisation as a core element and the natural next step of increased focus on cybersecure IT infrastructure is likewise universal for all solutions.

Ongoing projects that support the strategy



Situation in February 2022

3 SOLUTIONS

The joint Nordic work on solutions to the challenges facing the power system is under way and in this chapter, we present the current status of some of the more important Nordic topics. The topics covered here is not an exclusive list of the work done to make the Nordic power system ready to face the future challenges as most parts of our tasks are affected and much effort is also put into national changes. Further information can be found in each TSO's national development plans.

3.1 Ensuring high market capacity and reliable operations

The green transition will increase complicity and volatility in the electricity market. The transition also opens the electricity market to new participants, new business models and a consequential demand for development. This requires the market to adapt and become more flexible and more open to new ways of doing things. The Nordic TSOs collaborate closely together with each other and with market participants to establish a future market infrastructure that enables a continued cost-effective and reliable operation. Hence, a flexible market based on renewable energy, with considerably offshore wind generation and a much more sector integrated energy system.

With the Nordic Regional Security Coordinator (RSC) (Chapter 3.2.1) as a cornerstone for an even tighter Nordic cooperation, the market solutions strive to ensure high transmission capacity to the market in a way that supports flexibility and more truly reflects the physical typography of the common Nordic grid. Flow-based market coupling, and capacity allocation (Chapter 3.1.1) will improve the common Nordic capacity calculation, ensuring more capacity for the market and more dynamic adaption in a volatile market. A 15-minute market time unit (MTU) for intraday and intraday auctions (Chapter 3.1.2) will provide trading opportunities that are closer to actual delivery, thus enhancing the flexibility of the wholesale market. Possible changes to the bidding zones (Chapter 3.1.3) will reflect the structural bottlenecks resulting from new production and consump-

tion in the most optimal way. A 15-minute market resolution (Chapter 3.2.2) will reduce imbalance risks in a more volatile market for both market participants and system operators. These solutions will become core elements of the future market infrastructure and pave the way for further developments, as detailed in the common Nordic TSO strategy for wind power and sector integration.

3.1.1 Flow-based market coupling and capacity allocation in the Nordic region to ensure better utilisation of the grid

Because grid investments and grid reinforcements are processes with a longer-term focus, optimised use of existing infrastructure will provide more immediate results. Optimisation will be about developing improved data-based IT solutions for operational planning and control, such as the implementation of flow-based market coupling. Indeed, by introducing flow-based market coupling, an optimised balance between market facilitation and TSO system operations can be established: maximum trading opportunities for market actors, without sacrificing the operational security of the Nordic power system. Also, flow-based gives the TSOs better tools do handle congestion that occurs in new parts of the grid. For example, the Swedish West-Coast cut can be managed more optimally in a flow-based market coupling environment than is possible today. This also implies that it would be easier for the Nordic TSOs to make at least 70 percent of the capacity available to the market, as required by *The Clean Energy Package*.

Flow-based market coupling is the target model, as laid down in the relevant European regulations and guidelines. The Nordic TSOs, together with the Nordic RSC and the Nominated Electricity Market Operators (NEMOs), are currently in the process of implementing flow-based market coupling in the Nordic region. An internal parallel run has been operating from mid-2021, testing data, systems and processes. The expectation is to move to an external parallel run in Q1 2022. The external parallel run will function as a learning by doing period for all stakeholders involved. While the market is operated using the current net transfer capacity (NTC)-based market coupling, the TSOs and the Nordic RSC will, in parallel, perform a flow-based capacity calculation and the market outcome will be simulated together with the NEMOs using actual order books. Both the flow-based capacities and the flow-based market coupling simulations will be shared publicly. This will allow all stakeholders involved to get acquainted with the flow-based capacities and the corresponding market outcome. The external parallel run will continue for a period of at least one year.

As the introduction of the flow-based market coupling represents a major change in the Nordic power market, proactive stakeholder involvement is key. Thus, stakeholder communication and involvement with regard to the development of the Nordic flow-based capacity calculation methodology began at a very early stage. Activities included consultations, general national and Nordic stakeholder meetings, as well as dedicated discussion forums with national regulatory authorities (NRAs) and nominated stakeholders, newsletters, an information platform (website) and dialogue/bilateral discussions. With the start of the external parallel run, the efforts are being geared for stakeholder involvement. The discussions are changing from theoretical material and/or artificial examples to real simulations and corresponding data. The goal is to guide and assist all stakeholders, to ensure stakeholders are ready for the go-live of flow-based market coupling, and thus to ensure that go-live will be successful towards a successful flow-based coupling go live market.

The Nordic RSC is supporting the TSOs in several areas of operational planning, from flow-based capacity calculation and security analysis to adequacy analysis and outage coordination – all focusing on the optimal market availability of the Nordic power system and sustained security of supply. The basis for all analysis and calculations in the Nordic RSC is the detailed Nordic data model developed by all TSOs in recent years. This allows for a fully data-based approach, and transparency in methods and calculations for planning operation of the Nordic power system ahead of real time.

3.1.2 Enhancing the flexibility of wholesale markets

Flexible wholesale electricity markets, in both day-ahead and intraday time frames, are an essential component in enabling market parties to obtain a balanced position through trading and ensure operational security for the TSOs. Following the implementation of a single price for imbalance settlement, the Nordic TSOs and the NEMOs operating in the Nordic

area continue the work of implementing a 15-minute imbalance settlement, a 15-minute MTU in the intraday market, and in the day-ahead market by 2024. The development is driven by common European legislation, and in addition to increasing the flexibility of the wholesale electricity market, the shorter MTUs will result in enhanced system security and smaller imbalances for market parties.

To ensure that the Nordic market is ready to implement the 15-minute MTU, Nordic TSOs and NEMOs established a joint implementation project in the spring of 2021 to map and coordinate all the technical and procedural changes necessary to make a transition to the new standard MTU. The key changes relate to ensuring that the capacity management and communication systems of Nordic TSOs are capable of handling and processing capacity management and capacity and market coupling results in a 15-minute granularity.

As generation and consumption become more variable with the transition to a low-carbon energy system, a move to shorter market time units (MTUs) in traded products will enable trading that more closely matches the physical needs of both the supply and the demand side. Thus, Nordic TSOs and NEMOs active in the Nordic markets are working towards implementing a 15-minute MTU in intraday markets and day-ahead markets by 2024. This development is driven by the requirements set out in European legislation governing the coupling of the European day-ahead (Single Day-Ahead Coupling – SDAC) and intraday markets (Single Intraday Coupling – SIDC). Replacing the prevailing standard MTU of 60 minutes by 15 minutes will be enabled by the implementation of the 15-minute imbalance settlement period (Chapter 3.2.2.).

Another major Europe-wide development project is the introduction of intraday auctions (IDAs) scheduled to go live in late 2023. The implementing of IDAs is also a requirement stemming from European regulations and will complement the existing intraday market of continuous trading. At go-live there will be three auctions: an opening auction at 15.00 CET D-1, a second auction at 22.00 CET D-1 and a third, within-day auction at 10.00 CET. IDAs will offer market parties an alternative platform for trading and enable the pooling of market liquidity in the intraday time frame. Having the trading option of auctions closer to real-time than the prevailing day-ahead auction of SDAC will enhance market flexibility and provide TSOs with a superior outlet for new releases of cross-zonal capacity in the intraday market, and further improve the opportunities for market parties to reduce their imbalance settlements.

In addition to working towards the implementation of 15-minute MTUs and IDAs, Nordic TSOs remain actively involved in the range of ongoing initiatives to continually upgrade and improve the performance of the SDAC and SIDC market platforms. Ensuring the high performance and robustness of the European market coupling algorithms and IT systems is a pan-European effort requiring close collaboration between TSOs, NEMOs, system vendors and stakeholders.

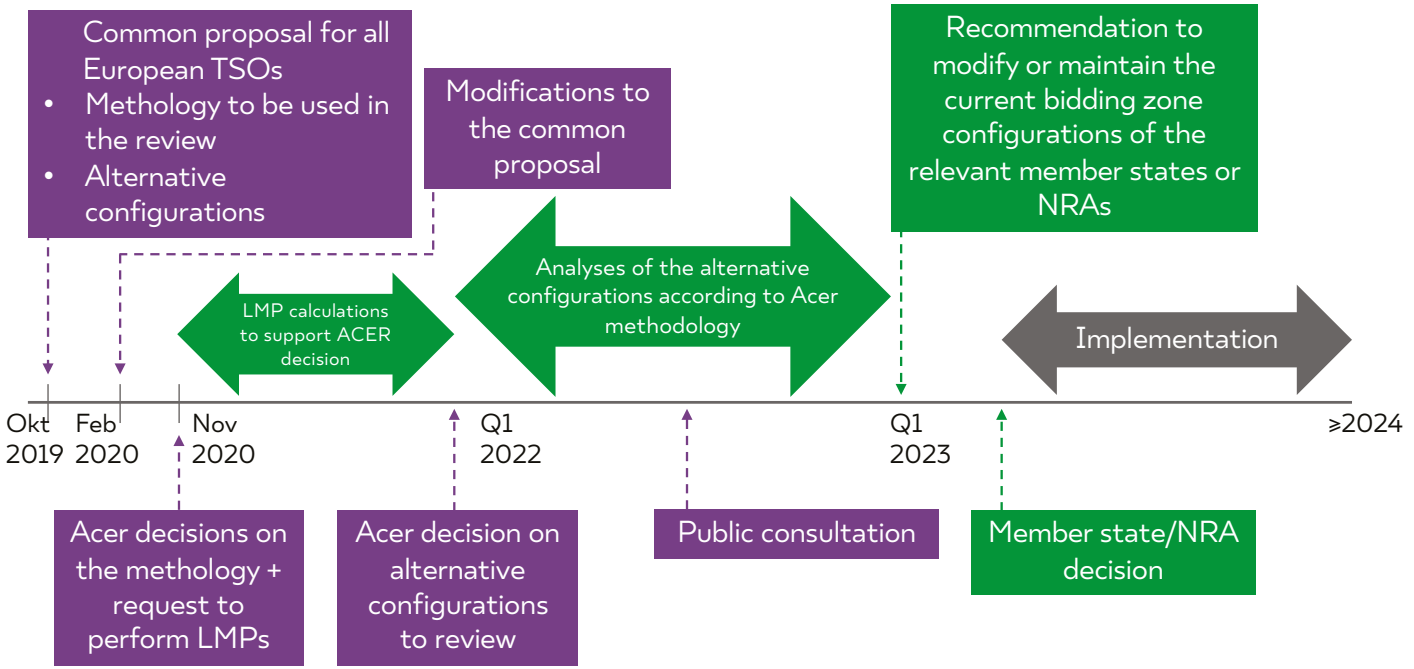
3.1.3 Bidding zones to handle congestions

Bidding zones are a cornerstone of the Nordic and European integrated electricity market and are based on the core principle that they should reflect structural congestions in the physical electricity grid. Keeping bidding zones aligned with developments in production, transmission and consumption driven by the green transition is therefore key, in terms of supporting secure operation of the power system, trading opportunities and social welfare, so that bidding zones in the future still give the right price signals and reflect real constraints in the grid.

According to European legislation, the bidding zone configurations in the EU shall be reviewed on a regular basis to make sure they are defined in an optimal way. The Nordic TSOs are currently involved in a pan-European study in which alternative bidding zone configurations are defined based on the expected presence of structural grid congestion in 2025. These configurations will be compared with the current configuration based on multiple perspectives such as economic efficiency, operational security and cross-zonal trade opportunities. The result will be a recommendation to the EU member states to either modify or retain the current bidding zones.

The review process is described on an overall level in the figure

Overall timeline for the bidding zone review



In late 2020, ACER decided on the methodology to be used in the bidding zone review, which also includes a request for results from so-called locational marginal pricing simulations (LMPs)[1]. The Nordic TSOs are currently working on this task and the results will be used by Acer to determine the alternative configurations to be studied further in the review of the Nordics. A similar process is also ongoing for continental Europe and Ireland. For the Nordic area, the following three configurations are under consideration:

1. A merger of Sweden's two southern bidding zones
2. A new bidding zone for the Stockholm Metropolitan Area
3. To divide Norway's northernmost bidding zone into two bidding zones

The decision from ACER on which alternative configurations to study and compare with the present bidding zones configuration is expected during the first quarter 2022. After this time, the TSOs have one year to perform the review, according to the requirements and criteria given in the ACER methodology and submit a proposal either to modify or retain the current bidding zones. Six months after the decision from ACER on new bidding zone configurations, a consultation will be held. Any changes to the current bidding zones will be implemented at the earliest by late 2024.

3.2 Balancing towards new and more efficient system operations

Wholesale electricity markets are designed in such a way that supply of electricity will meet the demand before the delivery. However, they do not ensure the operational security of the power system in real time. The Nordic TSOs stabilise and balance the system and keep frequency and grid constraints within secure limits to ensure the security of supply at all times.

The characteristics of the Nordic power system are changing. Nordic TSOs are working together to find new solutions for power system operation that meet the challenges of the future. Three major development streams are ongoing in the Nordics which are aiming at more efficient, harmonised and secure system operations. First, the transition to the Nordic Regional Coordination Centre (RCC) enhances the collaboration of operational planning in the Nordics and, for example, sizing of reserve capacity (Chapter 3.2.1). Second, the renewal of the Nordic balancing model will introduce a higher degree of automated operations, 15-minute time resolution and will finally enable participation in the harmonised European balancing market platforms (Chapter 3.2.2). The Nordic TSOs are also introducing new ancillary services and harmonised technical requirements for the frequency containment reserve to enhance the Nordic reserve markets (Chapter 3.2.3).

As more renewable energy sources are introduced into the power system, there will be a greater need for flexibility resources and active participants in the markets. The Nordic TSOs are not able to handle the future challenges on their own. We are working together with stakeholders to succeed in the green transition.

3.2.1 Transition to a Regional Coordination Centre enhances Nordic cooperation

The Nordic Regional Security Coordinator (RSC) office is a cornerstone of Nordic TSO cooperation, increasing regional and pan-European coordination and operational collaboration in all time frames of operational planning and daily operation. The enhanced coordination provides both system operators and market actors with a better overview of the entire Nordic electricity system, and the overall target is to optimise the Nordic societal benefits of the power system operation and ensure the security of supply.

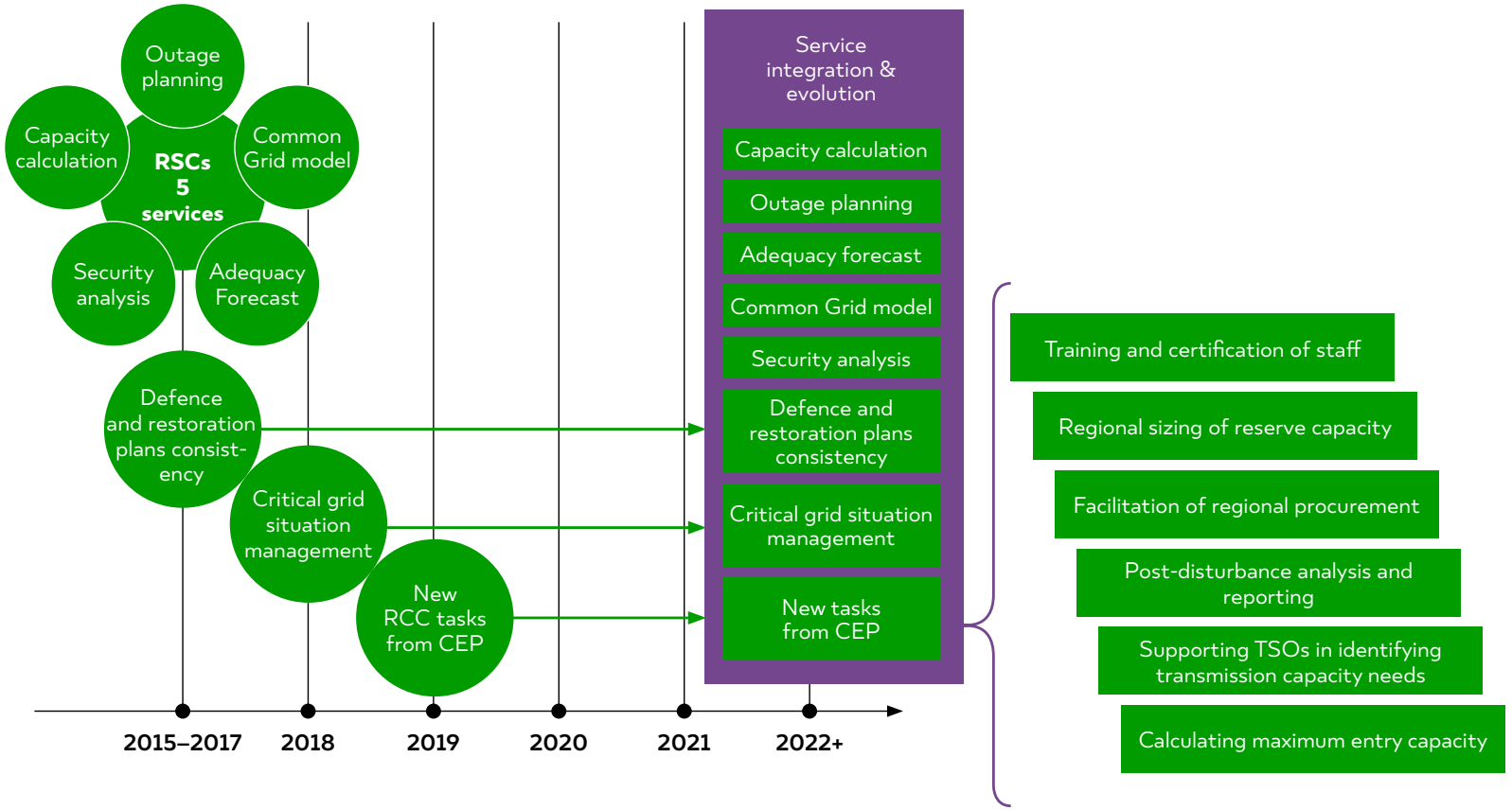
The Nordic RSC office provides both legally mandated and optional tasks. The European regulation requires the RSC take charge of a range of tasks within operational planning services, such as flow-based capacity calculation, capacity calculation and adequacy analysis. Beyond the mandatory tasks, the Nordic TSOs have delegated other tasks such as providing coordination between Nordic, Baltic and continental TSOs and RSCs to tackle potentially critical grid situations.

[1] Also known as *nodal pricing*. In this kind of market modelling, all transmission constraints are taken into account in the optimisation, giving values for power in each node. This means that the results could be used to analyse the presence of internal and cross-border structural congestion.

The basis for all analysis and calculations in the Nordic RSC is the detailed Nordic data model developed by all TSOs in recent years. This model allows for a fully data-based approach, and for transparency in methods and calculations. Together with the Nordic transparency on planned outages (NUCS), this will give stakeholders the option to integrate this information in their own forecasting and calculation models.

The EU regulation (2019/943" Clean Energy Package") requires that the RSC role evolves into that of a Regional Coordination Centre (RCC). The new regulation sets out six new tasks that the RCC are mandated to take charge over. To comply with the regulation The Nordic RCC will be established as an independent company by 1 July 2022, will be owned by the 4 Nordic TSOs and will support the Nordic TSOs within the new tasks, all of which will focus on the optimisation of the operation of the interconnected regional Nordic power system for the benefit of society at large. The new tasks are shown in the figure. With the transformation, the Nordic RCC will be given an even larger role in the Nordic electricity system and will enhance the cooperation even more, as well as more tasks are under consideration and could be given to the RCC in the future, if requested by the TSO's.

The new tasks of Regional Coordination Centre (RCC)



3.2.2 Renewal of the Nordic balancing model substantially changes the way that market functions

The Nordic Balancing Model (NBM) programme will renew the Nordic balancing process. It will facilitate increased volumes of variable renewable energy, European market integration and improved balancing market efficiency, while maintaining operational security in the most cost-effective manner. The NBM roadmap includes the implementation of aFRR and mFRR capacity markets, a single price model, mFRR energy activation markets and a 15-minute time resolution. The last milestone in the roadmap is implementation of the European energy activation market platforms, MARI and PICASSO. A decision on when to connect to MARI and PICASSO is considered in the ongoing derogation process with Nordic regulators. The Nordic TSO proposal is to connect to MARI and PICASSO within the time frame between the go live of 15 imbalance settlement (22.5.2023) and July 2024, which is the latest date, according to the derogation window. Further information about the NBM programme and the latest updates are available on the website.

Imbalance settlement. An imbalance settlement model and imbalance pricing provide incentives for market participants to balance their trading positions. A new single imbalance price settlement model according to the ACER decision on 18/2020 on the harmonisation of the main features of imbalance settlement was implemented on 1 November 2021 in the Nordic countries. The single price-single position will enable balance responsible parties and other market parties to handle their imbalances more efficiently.

15-minute imbalance settlement period. Moving from a one-hour imbalance settlement and market resolution to a 15-minute resolution will enable market participants to balance their positions in a more granular time frame, thereby reducing structural imbalances in an efficient and market-driven manner. The go live date for the 15-minute imbalance settlement and the 15-minute intraday market is 22 May 2023. The go live date for the 15-minute intraday market is currently re-assessed at the time of publishing.

Modernised ACE. The new Nordic balancing model involves a transition from controlling the frequency of the power system at a Nordic level to a model based on Area Control Error (ACE) similar to that of continental Europe. The model introduces the balancing of individual bidding zones and is a prerequisite for joining the upcoming European balancing market platforms. Compared to standard ACE-based operations, the new Nordic model will apply cross-border imbalance netting and balancing reserves. The NBM calls it *modernised* ACE. While ensuring clear roles and responsibilities among balancing participants, the main benefits of the new balancing model include better opportunities to participate in the upcoming European balancing markets. Furthermore, the new balancing model will improve frequency quality and overall contribute to an improved security of supply.

Capacity and energy markets for aFRR and mFRR. Balancing capacity markets are needed to ensure availability of adequate real-time balancing resources in all situations. Sufficient aFRR capability in the Nordic region is needed to ensure a safe transition to the updated Nordic balancing model, including a 15-minute time resolution. The Nordic TSOs are currently preparing the Nordic cross-border aFRR capacity market. A go live of the Nordic market is planned to take place earliest Q4'22. The Nordic TSOs will have a stepwise onboarding of national markets, utilizing the new Nordic IT platform, in the period between November 2022 and up to the go live of the Nordic market. One of the major milestones in the NBM roadmap is the introduction of a new method for mFRR activation, including the transition to a 15-minute imbalance settlement period. To implement these changes, a high degree of automation in the mFRR energy activation market is needed. Implementation of a modernised ACE will be completed by the introduction of the European aFRR energy activation market. Each load frequency control (LFC) area will then have its own aFRR controller that can regulate balance in that particular area.

Stakeholder involvement in NBM

The NBM programme has been focusing on stakeholder communication by planning and implementing communication via different channels and forums. The objective has been an open discussion regarding the upcoming market and technical changes that will influence all market participants. Stakeholders have been involved in the NBM stakeholder reference group, which is a high-level forum for discussions and sharing of information in both directions – from TSOs to stakeholders, and vice versa. There have been several webinars for a wider audience focusing on project-specific topics with the option to ask questions and give feedback. The programme has its own website that includes up-to-date information. In addition to mandatory consultations, the programme has collected feedback by organising additional consultations and questionnaires.

The complex programme and its legal framework impose challenges on the timetable of the regulatory processes. The programme having several regulatory processes, TSOs and NRAs have conducted regular coordination meetings and discussions.

3.2.3 Finding new ways to ensure high quality frequency

Inertia and FFR. Inertia is the power system's ability to withstand frequency changes due to resistance resulting from the kinetic energy of the rotating masses synchronised to the power system. During times of low inertia, a large and sudden power imbalance, for example, due to the sudden disconnection of a large generation unit, can cause large, instantaneous frequency deviation and endanger operational security. To support frequency containment reserve for disturbances (FCR-D) in situations of low inertia, the Nordic TSOs have implemented a new reserve product *Fast Frequency Reserve* (FFR). The TSOs procure FFR in times of low inertia based on common technical requirements.

The TSOs are currently assessing long-term power system development scenarios and the consequences of introducing increasingly more wind and solar power on power system inertia. Preliminary results indicate that periods of low inertia will become more common when moving towards the mid-2030s. Towards the mid-2040s, inertia levels are expected to decrease further, and the scenarios show periods of very low inertia. Such low inertia levels would call for new solutions for power system operation.

New FCR technical requirements. The Nordic TSOs have been gradually developing new harmonised technical requirements for the frequency containment reserve for normal operation (FCR-N) and frequency containment reserve for disturbances (FCR–D). The goal of the new requirements is to ensure a good level of security of supply in the transition towards a clean and integrated power system. Harmonised requirements will also help market participants operate across the Nordic region and ensure that the procured reserves fulfil the needs of the power system, regardless of which country they are delivered from.

Together with reserve providers, the TSOs piloted the new requirements during the latter part of 2021. The goal is to start implementation of the new requirements during 2022. With the implementation of the new requirements, the reserve providers need to perform tests to show compliance.

[2] NGDP2021

FCR-D downwards. As of 2022, the Nordic TSOs will procure a frequency containment reserve for disturbances (FCR–D), also for downwards regulation. FCR-D downwards is needed to handle large over-frequency disturbances, particularly due to the introduction of new interconnectors from Norway to Germany and the United Kingdom.

3.3 Creating the foundation for the future energy system

The development towards a climate neutral Nordic society is causing a rapid change in the energy sector. The drivers are electrification, new types of loads and the rapid growth in renewable electricity generation. A strong and stable Nordic power grid is the core of a future fossil-free Nordic energy system, making it a good place for future investment.

The Nordic TSOs are constantly collaborating to enable the clean energy system of the future and solve related challenges. A joint Nordic development of the transmission grid is an important part of this collaboration. It is being achieved through the work with the Nordic grid development reports (NGDP), which are published every second year. In general, NGDP describes the main drivers of the changing Nordic power system, as well as planned and ongoing grid developments to meet expected future needs. The recently published Nordic grid development report[2] (NGDP, Nordic Grid Development Perspective 2021) presents a common

Nordic scenario that reflects the development towards a climate neutral Nordic society, with Nordic consumption increasing from today's approximately 400 TWh to 655 TWh by 2040, as well as an overview of future system needs. The report also presents a Nordic view of the selected focus areas: North-South power transfer, resource adequacy and offshore wind power in the future system. (In addition to the Nordic scenario, there are national plans that deviate from the figures in the NDGP.)

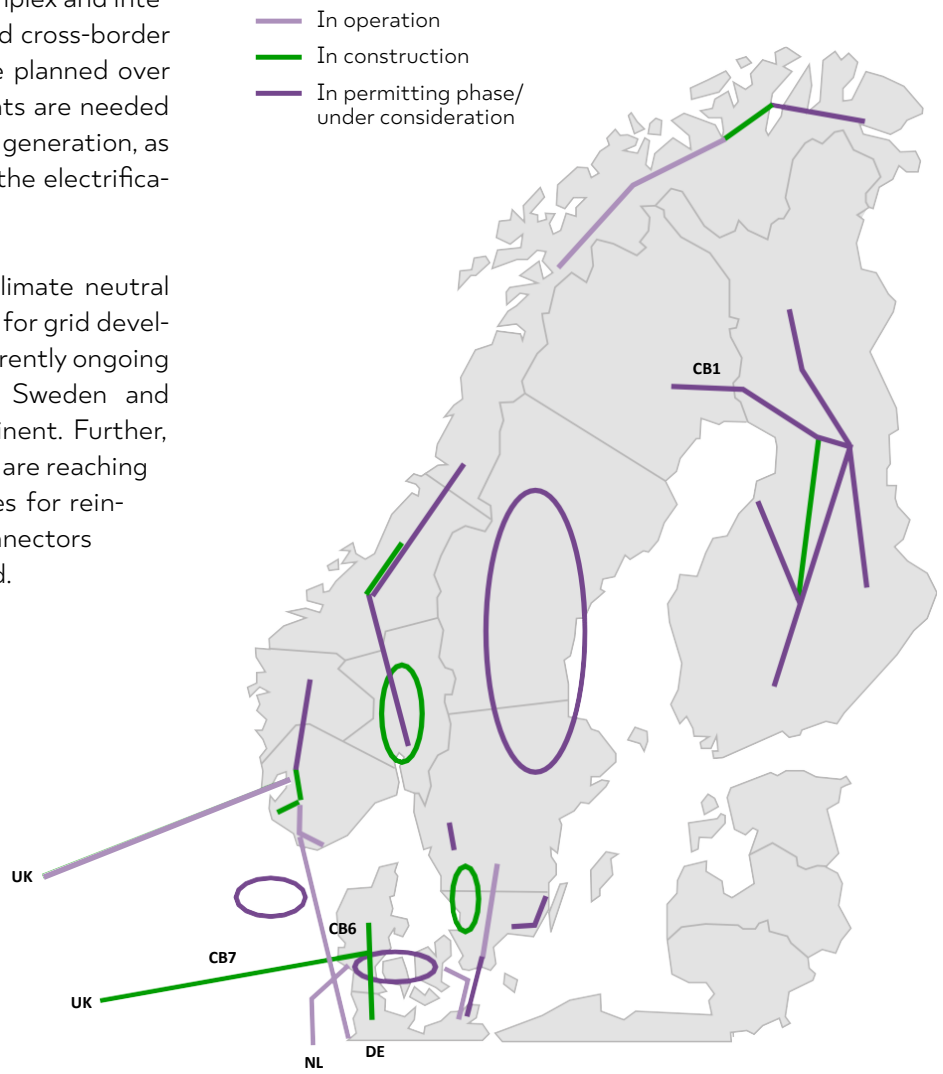
One of the main conclusions drawn in NGDP 2021 is that significant investments in the grid and cross-border connections are needed, and the current status of long-term system development is presented below. The studies also show that system adequacy will be a challenge in the future and that flexibility is one of the keys to the solution, as well as a strong transmission grid.

3.3.1 Long-term transmission system planning

The Nordic TSOs are preparing the grid for a future energy system that will become increasingly more complex and integrated. Significant investments in the grid and cross-border connections of more than EUR 25 billion are planned over the next ten years. However, more investments are needed to facilitate the growing renewable electricity generation, as well as meet the new demand resulting from the electrification of industrial processes, for example.

An analysis of future needs, based on the climate neutral Nordics scenario, indicated an increased need for grid development between bidding zones. There are currently ongoing investigations of interconnectors between Sweden and Finland and connecting Sweden to the continent. Further, several of the existing Nordic interconnectors are reaching their expected end of life. Thus, opportunities for reinvestment or replacement with new interconnectors with increased capacity are being investigated.

Map of projects of Nordic significance (from the NGDP report)



The projects shown in the figure above have been categorised as follows: national projects of Nordic importance, cross-border projects within the Nordic area and interconnectors to other synchronous areas. In addition, some of the projects have a reference to Projects of Common Interest (PCI) status. This is a status given by the European Commission to projects that have been deemed by the European Union to be Projects of Common Interest. There are three projects on the current PCI list (IV): the Aurora Line (CB1), connecting Sweden and Finland, the West Coast line, connecting Denmark and Germany (CB6) and the Viking Link, connecting Denmark and the UK (CB7).

The Nordic TSOs focus on the development of the Nordic power system that is based on creating the highest value for society and that leads to a carbon neutral future. Several studies indicate that the volatility in the future power system is increasing, but the most optimal solutions are not always to build more transmission grids; other means are also needed. One is flexibility in demand and generation and as volatility increases, so does the need for flexibility. Flexibility is required to develop and operate future system in an optimal way. Flexibility resources, such as demand-side response, P2X and EVs will be essential in the future power system and are essential from a system perspective. Furthermore, these resources will also play an important role in how future adequacy issues can be solved. It is expected that there will be profitable ways to operate them in the future system. The Nordic TSOs are sharing best practice and encouraging development in this area.

3.3.2 System adequacy

System adequacy is essentially a question of whether supply is sufficient to meet demand at all times. The power margin has been used as a metric to gain an overview of the adequacy situation in the Nordics. The value is calculated as the difference between each hour's average production and consumption. A positive power margin indicates hours with excess available power production and thus available export capacity, and vice versa for a negative power margin.

The transmission grid is a valuable enabler for the exchange of resources between regions in the Nordics and neighbouring countries. For example, analysis show that the number of hours with a negative power margin is much lower at a common Nordic level, compared to the sum of national values for the Nordic countries, i.e., some adequacy issues at the country level are resolved on the Nordic level thanks to the exchange of resources through the transmission grid. This also illustrates that a negative power margin in some areas might be the most optimal solution from an economic perspective and will lead to the most effective utilisation of resources.

4 NORDIC STRATEGY

4.1 Preface

The global energy transition is changing the Nordic energy landscape. Decarbonised electricity and the expected increase in its use are key to meeting the climate targets set by the Paris Climate Agreement. The Nordics have an abundance of clean[3] energy, but current clean electricity generation is not sufficient to meet the forecast increase in electricity consumption. The Nordic region needs more clean electricity and has particularly good resources for the expansion of onshore and offshore wind power. Sector integration provides the connection between the increasingly variable forms of electricity generation that are replacing other traditional energy sources and new uses for electricity in a variety of sectors.

With a growing amount of variable renewable power, generation adequacy and a low level of inertia can challenge the future electricity system. In this respect, it is vital to safeguard the generation of hydropower and nuclear power in the Nordic countries. A specific challenge for the Nordic region is also the seasonal variation in electricity consumption that calls for innovations and new solutions regarding long-term flexibility and storage. Another important factor that contributes to short-term adequacy issues is the geographical decentralisation of wind power generation, which requires interconnections in order to transport the electricity across the region to where it is needed.

To respond to the energy transition challenges, the four Nordic electricity transmission system operators have prepared a Nordic TSO strategy for wind power and sector integration, spanning towards 2030. The focus of the strategy is on joint Nordic TSO activities that have a direct link to the development of wind power and sector integration in collaboration with stakeholders. Wind power development and sector integration are areas in which future development and their pathways are dependent on multiple actors. Stakeholders have provided valuable input for this strategy and will be key collaborating partners in the strategy's implementation.

The strategy comprises a Nordic vision and includes themes for measures to achieve the vision. The strategy will also recognise and consider the developments and requirements taking place at the EU level and in the surrounding regions, such as the Baltic and North Sea regions.

The highlights of the Nordic TSO strategy are centred around the following issues:

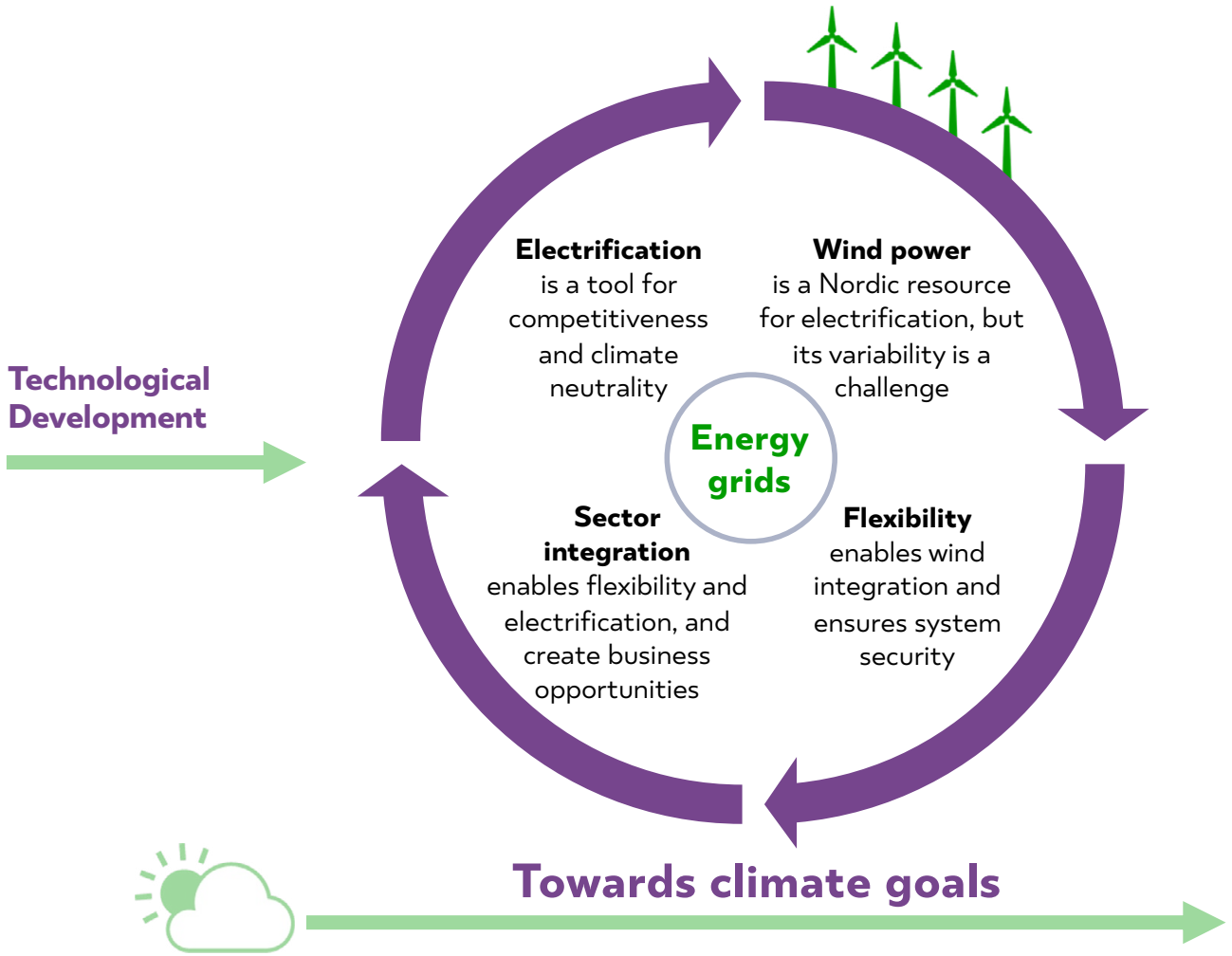
- Broad cooperation across all energy sectors and stakeholders is vital
- Nordic TSOs must develop and maintain adequate infrastructure for effective markets and renewable energy sources
- All sources of flexibility – in consumption, energy storage and generation – are needed for balancing and congestion management
- Easy and equal market access and proper incentives for all energy resources are required to ensure generation adequacy and to unlock flexibility and system services.
- Power system planning, including the Baltic and North Sea regions, must consider all energy sectors and types of infrastructure to enable optimisation of the entire energy system
- There needs to be streamlined processes to make the grid capacity and grid connections available in time.

[3] Here," clean" means CO_2-free or CO_2-neutral energy generation. This includes, for example, wind power, solar power, hydro power, nuclear power and biomass-based power generation.

4.2 The elements of success

The Nordic solutions for achieving the climate goals are concentrated on electrification that utilises clean electricity. In order to enable a huge increase in variable and weather-dependent electricity in the Nordic electricity system, we need sector integration and flexibility provided by the various energy systems and their grids.

Electrification enables the replacement of fossil fuels, for example, by using electricity directly for producing heat for buildings and industry. Furthermore, electricity can be used to produce clean hydrogen, which can either be used directly in industry or can be further processed for multiple purposes. Electricity can also be used instead of fossil fuels as a direct or indirect fuel in the transport sector. Thanks to well-functioning electricity markets and good wind conditions, electrification can enable an efficient and competitive energy system. Climate neutrality in the Nordics will require moving from fossil-based fuels to clean and renewable electricity.



Wind power is a readily available resource in the Nordics: geographically large rural areas for onshore wind power, long coastlines with an abundance of shallow waters for offshore wind power and good wind conditions. The Nordic power system uses a high volume of climate-neutral energy that attracts stakeholders with business models that benefit from such energy. However, power production using wind power has natural variability and is somewhat seasonally dependent, as cold winter days tend to be characterised by low levels of wind. Large amounts of wind power will increase price volatility and may affect stability. An increase in the share of wind power in the power system has to be supplemented by additional measures that ensure the stability of the entire power system.

Flexibility refers to the ability to react to the fluctuating needs of the power system and is one of the tools needed to maintain system security and also security of supply[4]. There are several sources of power system flexibility. These include electricity generation, consumption, storage, and transmission lines between bidding zones. During periods when wind power variability does not follow the variability in consumption, there is a need for flexibility to balance consumption and generation. The need for flexibility increases with increasing variable renewable energy penetration. Flexibility can also be used to limit the short-term peaks of power flows in the grid. The more flexibility that is available, the more opportunity there is to integrate wind power generation on a large scale into the system without compromising the security of supply.

Sector integration interconnects other energy sectors (e.g. heating, gas, transportation) to the electricity sector providing new electricity loads with flexibility potential and giving access to inexpensive and effective types of energy storage. This includes electrolysers for clean hydrogen production used as a source of flexibility for the power system, while hydrogen can be stored and transported whenever it is needed. Sector integration is a two-way street that not only enables electrification but often also results in electrification, i.e. the electrification of heat and gas production and road transport would not be possible without sector integration. New services and technologies are needed in relation to sector integration and would lead to new business opportunities, such as the coordination and/or optimisation of flexibility resources from both an energy system and resource owner perspective. These opportunities could be the result of efficient interaction between energy carriers that can compete on a level playing field.

Technological development is unlocking the emerging energy conversions that can be seen in the market today, new services and automation of systems, as well as utilising the opportunities offered by digitalisation, which is developing at a rapid pace. Many energy technologies are approaching market saturation, while other energy technologies still need to be developed in order to be commercially feasible. A robust digital foundation will enable future complex and interlinked energy systems to be controlled in a secure and reliable way.

Finally, **energy grids** connect generation and consumption in different energy sectors together and enable electrification and sector integration. The grids represent infrastructure in various energy sectors including the electricity, gas (both methane and hydrogen) and heat sectors.

[4] Here, system security mainly refers to the operational security of the power system, while security of supply also includes security of the distribution grid, generation adequacy and delivery to the end consumer.

4.3 The vision

Foundations of the vision

The prerequisites of the Nordic vision include excellent conditions for wind power, advanced electricity markets with easy market access and good co-operation among all stakeholders. This will provide a trustworthy basis for green investments while also maintaining a stable and reliable electricity system.

- **Good cooperation among stakeholders**
- **Excellent conditions for wind power**
- **Easy access to advanced markets**
- **Trustworthy basis for green investments**

The Nordic countries have a long tradition of cooperation among TSOs and stakeholders on all organisational levels and an example of this is the long history of wind power integration. This is crucial for identifying harmonised solutions and sharing resources. It also extends to engineering, as well as research and development in many business sectors.

The Nordic countries have excellent conditions for onshore and offshore wind power and there is easy access to advanced electricity markets. The economic conditions are stable on a national level. The high share of climate-neutral energy and, to some extent, the geography and climate are attracting new business, innovations and investors into sectors such as electrified transport systems, carbon-free steel production and data centres.

Building blocks of the vision

The vision is based on an adequate infrastructure, secure power system and an integrated electricity market where energy system is optimised.

Adequate infrastructure

enabling an integrated market for renewable energy resources, as well as direct and indirect electrification

Secure power system and integrated market

with market design supporting flexibility and secure system operation, and with a level playing field for all technologies

Optimised energy system

in which infrastructure is based on climate-neutral electricity and on the needs of stakeholders

An adequate infrastructure implies a situation in which predefined security of supply criteria and market needs are achieved on an optimised cost-benefit level. One cornerstone of infrastructure is adequate transmission capacity which, in this instance, not only refers to electricity transmission but also to the gas and heat grid for district heating, for example. The purpose of adequate transmission capacity is to fulfil the needs of customers and market players. Renewable energy resources are also addressed because of their importance to electrification and their role in transitioning to a clean energy system. Indirect electrification implies a situation in which electricity is used indirectly for decarbonisation and should be taken into account when developing adequate infrastructure. For example, clean hydrogen produced using electricity can be stored and transported in the form of hydrogen before being used by end users or for further refinement into clean e-fuels for heavy transport, ships, etc.

A secure power system and integrated markets requires market rules and design that are harmonised, at least in the Nordic region, to enable easy access and utilisation of all flexibility resources in the Nordic markets[5]. This would also prevent conflicting incentives and enable efficient coordination of flexibility resources on a cross-border level. In the long term, all energy markets (not only the electricity market) should become integrated on the market level as well as on the Nordic level in order to enable a complete system of energy sectors. A level playing field for all technologies and energy sectors guarantees a neutral and fair position for any technology that may support decarbonisation and the secure operation of the power system.

An optimised energy system implies a system in which energy is generated, converted, stored, transferred, exported and consumed in the form and at the location that is the most favourable from both a socioeconomic and a technical perspective. The infrastructure to be used not only covers electricity grids but also gas grids, EV charging infrastructure, district heating infrastructure and all infrastructure needed to facilitate clean energy generation, consumption and transmission according to the needs of stakeholders. An optimised energy system is the result of a joint effort between key players.

[5] *Markets* refers to different electricity markets such as day-ahead, intra-day and balancing markets, but also to other energy markets such as the gas market and possibly the heating/cooling markets.

The vision statement

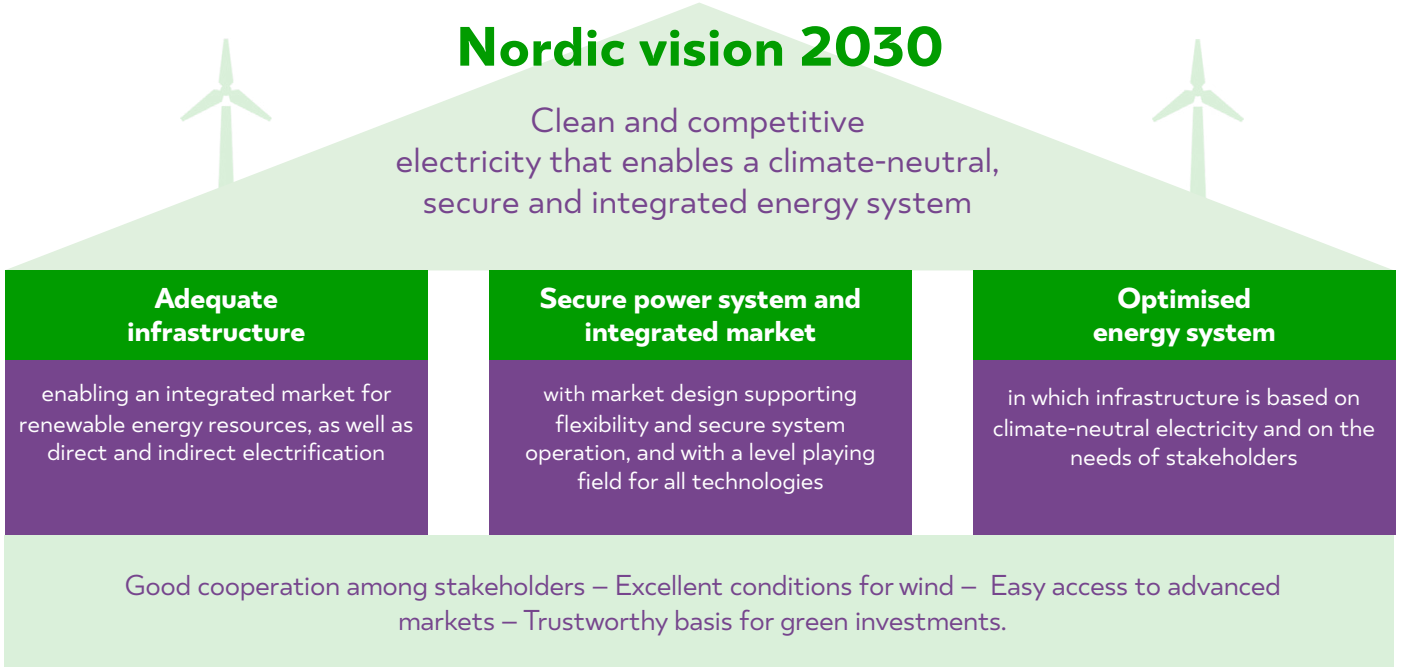
The vision of the Nordic TSO strategy is to have clean and competitive electricity that enables a climate-neutral, secure and integrated energy system.

By 2030, Nordic energy will be based on clean electricity generation. Competitive electricity prices are to be based on cost-efficient renewable power generation without subsidies. The role of TSOs will be enablers in addition to their responsibility for maintaining the electricity infrastructure and adequate security of supply.

Climate neutrality is based on common European and national climate targets. An integrated energy system combines different sectors and wind power, thereby creating an optimised energy system. An integrated energy system also addresses the importance of cooperation with stakeholders and among TSOs.

The vision applies to the Nordic energy system, but it also acknowledges the idea that offshore wind power may be located somewhere between the Nordic power system and the neighbouring power systems.

> **Clean and competitive electricity that enables a climate-neutral, secure and integrated energy system**



4.4 Strategic themes for measures

The grid is the platform that connects electricity producers and consumers. Hence, TSOs play a key role as enablers in sector and wind power integration together with other players, such as DSOs. TSOs provide access to the grid and markets for both consumers and producers. The objective is a system in which users and producers have favourable conditions to invest in the Nordics. While the investments in clean generation and demand facilities themselves will be carried out by other companies, the role of TSOs will be to enable such investments by electricity network development, as well as being responsible for the system operation and contributing to market design.

With the rapidly progressing energy transition and upcoming electrification, TSOs must create a platform for a clean electricity system at an unprecedented pace, while simultaneously ensuring that the future system will be secure. This requires good cooperation and communication between TSOs and stakeholders, both the existing stakeholders that we enjoy good collaboration with today, and new stakeholders in emerging sectors. Many of the necessary TSO measures still relate to core TSO business – for example, connecting new generation and demand, optimising the performance of existing power systems, building planned grid investments, facilitating players' access to the common markets, as well as secure operation of the power system. At the same time, new demand, generation, storage and grid technologies, as well as market mechanisms related to sector integration, require intensified development activities by all stakeholders.

The strategic themes for actions that the TSOs must take fall into three categories that reflect the building blocks of the strategy: Adequate infrastructure, Secure power system and an integrated market, and Optimised energy system.

Adequate infrastructure

- Build adequate infrastructure including the Baltic Sea and North Sea regions
- Speed up connection to grid
- Optimal utilisation and performance of the existing system
- Use the full transmission technology mix for further grid expansion

Secure power system and integrated market

- Ensure market access and financial incentives for all energy resources to provide adequacy, flexibility and system services
- Develop the requirements for new energy resources to ensure their flexibility and the system security
- Create tools to monitor flexibility and also forecast it at a Nordic level
- Introduce offshore bidding zones and integrate offshore solutions into the electricity market

Optimised energy system

- Develop tools and create cooperation models for holistic energy system planning
- Use ambitious wind power and electrification scenarios in system planning

4.4.1 Adequate infrastructure

Build adequate infrastructure including in the Baltic and North Sea regions

The increase in clean energy generation and new consumption sources will require new transmission infrastructure. When planning and building infrastructure, we must consider new sources of demand from different energy sectors, the impact of the location of new demand or generation on the socioeconomic welfare, as well as market solutions that are suitable for the offshore grid.

Adequate infrastructure reflects the necessary infrastructure in terms of economically efficient build-out and system planning that leads to total optimisation on the energy system level. TSOs must plan and optimise the electricity grid, taking into account other types of infrastructure, based on climate-neutral scenarios, while gaining insight into future needs for system planning and operation in order to make robust investments.

TSOs must be swift and accurate in providing the right solutions, at the right time and at the right location in order to maintain a secure power system and fulfil the needs of clean energy generation and new demand facilities. At the same time, TSOs work in the interests of society and take stakeholders' concerns into account.

The development of transmission capacity requires continuous and strong coordination between the Nordic TSOs, but also between the Nordic region and neighbouring areas such as the Baltic and North Sea region. There will be a greater need for coordination when the areas are more closely connected via strong HVDC capacity and common markets.

Speed up connection to the grid

Renewable power and new demand are being connected to the grid at an increasing pace. The speed at which transmission capacity is increased is often slower than the speed of building new renewable power plants or other demand/generation to be connected to the grid. Thus, there is a need to improve the speed of grid connection, including the reinforcement of transmission capacity.

TSOs must identify the main obstacles and/or time-consuming aspects of the process and how to make them more efficient, without compromising sustainability and cost effectiveness in either the development of power generation or transmission capacity, while ensuring societal acceptance. The development includes processes before the actual building of transmission lines, for example, an environmental impact analysis and its timing, permits and approvals, as well as TSOs' internal processes. In addition, solutions like a flexible connection agreement enables a customer to connect to the grid earlier than in a situation in which a reinforcement of transmission capacity is required before the customer can be connected. This concept will be further developed.

Optimal utilisation and performance of the existing system

While the need for new transmission capacity is increasing, the expectations of TSOs regarding cost efficiency and the ability to consider environmental aspects are also increasing. This motivates TSOs to innovate new smart solutions in which transmission capacity can be increased without building new lines. In addition to new solutions, sharing and coordinating best practices that are already in use among TSOs should also be considered. Regulation should also support this kind of development.

There is a need for a joint Nordic assessment of opportunities for increased utilisation and efficient operation of the existing grid through coordinated measures of engaging new types of flexibility through sector integration. Furthermore, several additional technical projects fall under this theme, such as dynamic line rating and series/shunt compensation. These projects are necessary to get most out of the existing infrastructure as the system around it experiences energy transition. Also, smart solutions through the use of big data and artificial intelligence for data analysis could enable power system operation that is closer to its limits.

Finally, TSOs must be transparent about current and future grid congestion and local differences in electricity systems. Only then will it be possible to optimise the location of new wind power production and new flexible demand, resulting in the balanced buildout of renewable energy, demand and transmission grids.

Use the full transmission technology mix for further grid expansion

A broad use of technologies when increasing transmission capacity is derived from the fact that new technologies offer benefits in terms of performance and cost-efficiency compared to traditional technologies.

Nordic TSOs use a wide range of technologies but will work together to push the development of new technologies, as well as utilise existing technologies. These are needed to build a system that is up to the challenge of electrifying the Nordic countries. These new technologies could include a higher voltage level than is used today, internal DC lines, meshed offshore grids, etc.

4.4.2 Secure power system and integrated market

Ensure market access and financial incentives for all energy resources to provide adequacy, flexibility and ancillary services

The right financial incentives and easy access for all available energy resources to the marketplaces is vital for sufficient adequacy, the growth in flexibility and provision of ancillary services.

The volatility in the future system is increasing meaning greater variation regarding adequacy, balances, flows and prices. The power balance in the Nordic system is already today negative in cold winter days and we have to rely on imports. As power generation is facing massive changes both in the Nordics and the rest of Europe with phasing in of variable renewables combined with decommissioning of thermal plants, the operation of the power system will be challenged. The need to assess generation adequacy and further develop efficient markets is a priority.

It is of great importance for an efficient market and secure power system operation that flexibility, in terms of both consumption and production, is active. Easy access to a well-functioning marketplace needs to be provided with financial incentives for all energy resources in order to ensure flexibility. In the short term, market signals should accurately reflect the existing situation in the power system, in terms of both time and geography. In the long term, investment incentives for flexibility resources are important to ensure adequacy, flexibility and ancillary services.

Balancing markets are being developed to initially have regional market platforms and then to connect the Nordic region to the European balancing energy markets. The Nordic Balancing Model programme and the introduction of 15-minute market time units across the different market time frames are key enablers for the growth of renewable energy. These changes will allow for more accurate pricing of flexibility. The 15-minute markets will be accompanied with major changes in system operation with needed automatization of system operation processes related to balancing and congestion management.

Non-frequency ancillary services (steady state voltage control, fast reactive current injections, inertia, stability, short-circuit current, black start capability and island operation capability) currently have no markets, with the exception of procuring fast frequency reserves nationally for low inertia situations. Markets will be developed for non-frequency ancillary services where they are feasible in order to have the necessary tools for managing power system.

Local flexibility markets are a promising option for managing grid constraints. To further improve the role and functioning of local flexibility markets, the aim is to integrate them with existing markets. Thresholds for participating in the ancillary services markets should be lowered, for example, by coordinating aggregation together with DSOs. Nordic TSOs will also actively participate in the development of the new European regulatory framework for demand- side flexibility.

Nordic TSOs will work towards ensuring a level playing field for all energy carriers and identify potential barriers to it within their areas.

Develop the requirements for new energy resources to ensure their flexibility and system security

New types of consumption and generation bring new features to the power system. A high ratio of converter connected energy resources will challenge the power system. Thus, it is crucial to ensure that renewable energy sources have the technical capability (within the inherent limits of the technology) to provide flexibility and system services, for example, requirements on functionalities for converter connected technologies, etc.

Demand-side flexibility will be crucial in a future power system with a large share of variable renewable energy. It is important to introduce requirements that enable the provision of flexibility on new consumption. What may constitute the necessary requirements for flexible consumption needs to be further analysed.

Technical requirements regarding new types of consumption and generation need to be updated to ensure system security. Examples of new resources include large offshore hubs, electrolysers, charging stations for electric vehicles and heat pumps. Connecting these resources to the power system may risk the security of supply if they are not properly considered in TSO requirements for connected resources. These requirements define the required functionalities for the connected resources to avoid negatively impacting the power system and to support system security instead (e.g. by enabling ancillary services).

Create tools to monitor flexibility and also forecast it at a Nordic level

Wind power and other weather-dependent generation cause rapid changes in the power system that can be monitored and understood on the system level. Thus, TSOs must have situational awareness of the power system on the Nordic level. This requires the ability to monitor and forecast changes, but also the ability to monitor the *need* and *availability* of the flexibility.

Monitoring is a necessary tool for understanding the need and availability of flexibility in the market, particularly when new flexibility resources from distributed resources and from different energy sectors will be in place. This requires continuous collaboration between TSOs, DSOs and other energy sectors. In addition, a forecast of the required and available flexibility is important in order to react beforehand to potentially challenging operational situations.

Introduce offshore bidding zones and integrate offshore solutions in the electricity market

The total power system should be considered as a single power system, either located onshore or offshore. In practice, this means that market design, regulation, roles and responsibilities should be similar to onshore and offshore grids, where appropriate.

Nordic TSOs will work towards the introduction of offshore bidding zones, which can be connected to each other and also more than one onshore bidding zone. Efficient system operation requires that TSOs have the same responsibility for onshore and offshore grids. Onshore and offshore market players should be given similar access to the reserve markets and similar technical requirements within the framework of secure operation and the anticipated imbalances of offshore bidding zones should be included in the reserve dimensioning. Offshore consumption, for example, hydrogen production, should have the same requirements and opportunities as onshore consumption within the framework of system security.

Offshore bidding zones leads also to close TSO cooperation with the neighbouring regions as the large offshore initiatives are located in the Baltic and North Sea regions.

4.4.3 Optimised energy system

Develop tools and create cooperation models for holistic energy system planning

Large-scale wind power, offshore and onshore, as well as the integration of different energy sectors, bring new elements to the planning of the entire energy system. At the same time, electricity markets are getting more integrated, and the optimisation of energy systems requires new tools and broader cooperation. The new planning tools not only include models that represent the dynamics of electricity generation (e.g. offshore wind power) and consumption from new sources, but also a better understanding of different stakeholders and their needs.

Furthermore, traditional electricity grid planning will change to more holistic planning in which more alternatives to traditional transmission lines will exist. For example, a gas or a hydrogen grid could be considered an alternative to an electricity grid in the Nordic cross-border planning. Holistic planning also covers different flexibility options to overcome high transmission situations without building new lines. For example, storing electricity or heat generated during the summer to be used in the winter or producing hydrogen that can be transported and stored via a new hydrogen infrastructure. This requires the development of models for application of long-term flexibility and other types of infrastructure for long-term energy system planning.

A new type of cooperation is needed in order to understand and optimise the wider energy system, including all energy sectors, flexibility potential and the needs of distribution system operators. Also, broad cooperation is required with the neighbouring regions of the Nordics, such as the Baltic and North Sea regions in which increasing offshore wind power will have a role. The developments in these neighbouring regions also affect the Nordic region. The planning of offshore grids for offshore wind power should from a part of the holistic energy system planning. Offshore grid planning also requires planning principles to be updated.

A new type of cooperation is needed in order to understand and optimise the wider energy system, including all energy sectors.

Use ambitious wind power and electrification scenarios in system planning

Large-scale wind power development enables ambitious electrification. Nordic TSOs will assess ambitious Nordic wind power and electrification scenarios that reflect the potential of sector integration, both onshore and offshore wind power, to identify possible locations and the required new grid capacity. The assessment will constitute a guideline for more profound system planning and will be the first step towards holistic planning. The assessment will be conducted at the Nordic level (as part of the biennial Nordic Grid Development Perspective) and also from a European perspective, taking into account the work conducted in the ENTSO-E Ten-Year Network Development Plan (TYNDP).

4.5 Strategy implementation

The development of a common strategy for the four Nordic TSOs is only one step towards fulfilling the vision of enabling *clean and competitive electricity that enables a climate-neutral, secure and integrated energy system*. The strategy that has now been formulated and agreed on a joint Nordic level towards 2030 must be implemented if the vision is to come true.

The everyday prioritisation and implementation of joint activities is being organised by five Nordic Committees:

- Nordic Planning Group (NPG)
- Regional Group Nordic (RGN); system operation
- Nordic Market Steering Group (MSG)
- Nordic IT Group (NIT)
- Nordic R&D Group (NRD)
- The Nordic Balancing Model Programme (NBM programme)
- The Nordic Capacity Calculation Methodology (CCM-project)

These committees are already organising and developing common Nordic solutions. The committees will now start implementing the strategy by allocating common resources, launching activities and monitoring progress – with the primary aim of delivering on the strategy. Some important initiatives are already ongoing, while other strategic measures entail starting new and concrete projects. One of the existing projects that already forms part of the strategy is the Nordic Balancing Programme, introducing a 15-minute imbalance settlement period, the increased coordination of operational planning among the Nordic TSOs through the Nordic Regional Coordination Centre and the new coordinated capacity calculation. It is up to the committees to continuously develop new projects ensuring the realisation of the strategic challenges. This work started with the development of an implementation plan.

A strategy implementation plan contains the crucial activities that the Nordic electricity TSOs need to jointly work on and it is presented here: *Appendix 1*.

The Nordic TSOs are committed to ensuring that the strategy succeeds in guiding the work of the individual TSOs, as well as the common work conducted by the committees. In this way, the progress of the implementation plan will be monitored and updated at least on an annual basis. The status of the strategy and the implementation plan will be published in the forthcoming bi-annual solutions reports, to ensure that the progress is visible to all stakeholders. This will allow stakeholders to consider the current developments in the sector, as well as newly identified tasks that might emerge towards 2030 and ensure that the developments are on track.

Abbreviations

- ACE: Area Control Error
- aFRR: Automatic Frequency Restoration Reserve
- CET: Central European Time
- COP26: United Nations Climate Change Conference
- DSO: Distribution System Operator
- FCR-D: Frequency Containment Reserve for Disturbances
- FFR: Fast Frequency Reserve
- FCR-N: Frequency Containment Reserve for Normal Operation
- IDA: Intraday Auction
- LFC: Load Frequency Control
- MARI: Manually Activated Reserves Initiative
- mFRR: Manual Frequency Restoration Reserve
- MTU: Market Time Unit
- NBM: Nordic Balancing Model
- NGDP: Nordic Grid Development Perspective
- NEMO: Nominated Electricity Market Operators
- NUCS: Nordic transparency on planned outages
- NRA: National Regulatory Authorities
- NTC: Net Transfer Capacity
- PCI: Projects of Common Interest
- PICASSO: Platform for the International Coordination of the Automatic frequency restoration process and Stable System Operation
- R&D: Research and Development
- RCC: Regional Coordination Centre
- RSC: Regional Security Coordinator
- SDAC: Single Day-Ahead Coupling
- SIDC: Single Intraday Coupling
- TSO: Transmission System Operator
- TYNDP: Ten-Year Network Development Plan

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