Main grid development plan 2022–2031

FINGRID

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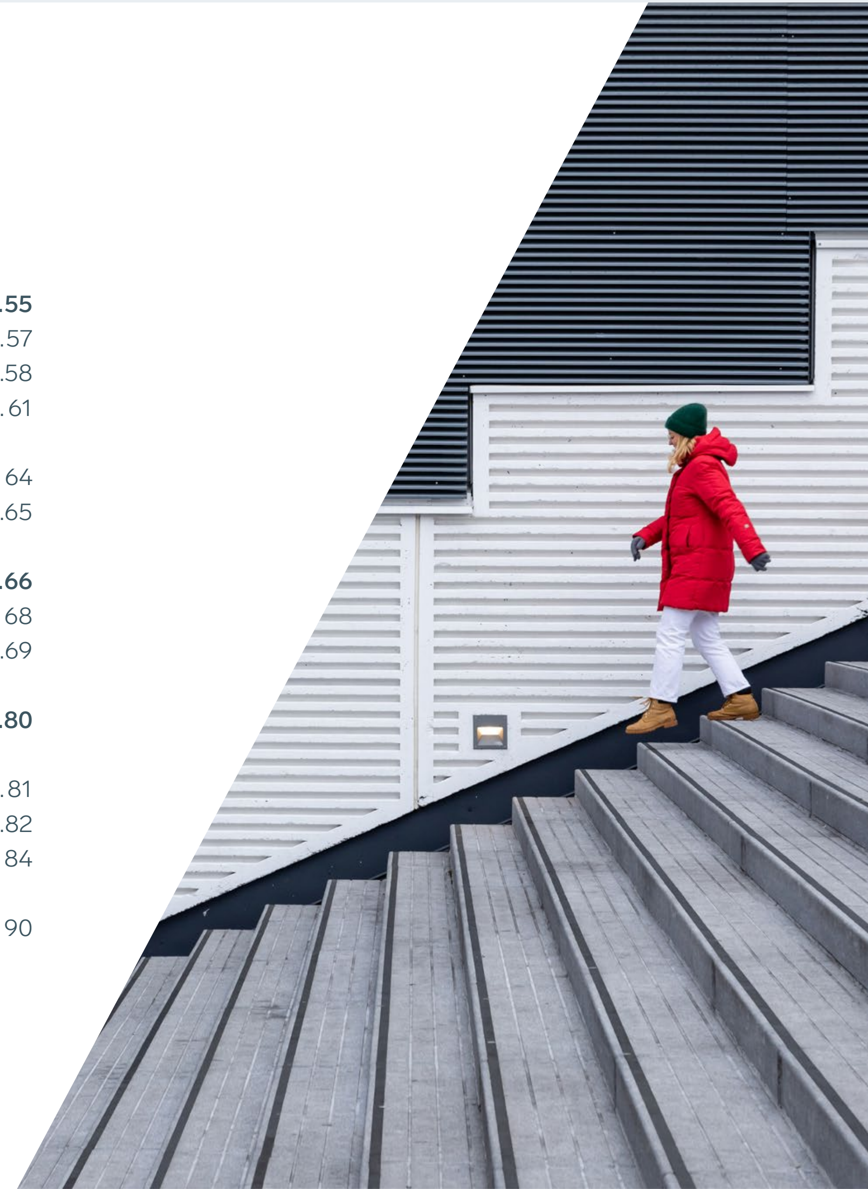

Summary

Developing the main grid to meet the needs of customers and society is one of the core tasks of Fingrid Oyj, the company responsible for the power transmission system in Finland. Continuous development of the main grid ensures that the electricity transmission grid and the entire electricity system meet the requirements set for them in a changing operating environment.

The main grid development plan presents the development needs of Fingrid's main grid and planned investments for the next ten years. The development plan is based on regional grid and connection plans compiled by Fingrid in cooperation with its customers, and it is coordinated with the development plan for the Baltic Sea region, as well as the Ten-Year Network Development Plan (TYNDP) covering the entire European Union.

The preparation of the grid development plan is subject to the provision of the Electricity Market Act, and the plan is updated every two years. The core content of the main grid development plan shall be a description of how, and using what kinds of investments, the responsibility for main grid development and the quality requirements of main grid operations are to be fulfilled.

Changes in the operating environment

The energy sector plays a key role in combating climate change. As the structure of electricity generation becomes increasingly lower in emissions, the power system is in the midst of unprecedented change, and it faces new challenges. The new, low-emission generation structure will give rise to occasional shortages of power and transmission capacity and flexibility, and system inertia and short-circuit power. At the same time, society is becoming more electrified and dependent on electricity. The power system of the future is expected to provide even greater reliability in order to safeguard the vital functions of society.

The shift in the generation structure is a major driver of changes in Fingrid's development of the main grid. The increase in weather-dependent generation, large new nuclear power plant units, a decrease in the amount of generation that can be readily regulated, the geographic location of new generation facilities in the main grid, and the pace of elec-

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trification in society are key trends from the standpoint of network development.

In its grid plan, Fingrid strives to prepare for a difficult-to-forecast future by means of different scenarios. The adequacy of the network will be tested against these scenarios with the purpose of finding strengthening needs that are common across the scenarios. Based on this, the network can be strengthened proactively. In addition, efforts are made to find criteria that would trigger the need to strengthen the network and will then monitor the trends in these criteria. Currently, the most critical factors that are monitored and that influence the development plan are the geographical location of wind power and consumption concentrations due to electrification, as well as the pace of electrification of transport and industry.

Electricity consumption has significant growth potential in the future, but a large portion of the potential will not be realised by 2031. However, electricity generation is expected to increase significantly. Wind power may become the largest form of electricity generation in Finland before the end of this decade. Generation and consumption in the electricity system must be in balance at all times, which means that as electricity generation becomes less adjustable, electricity consumption must correspondingly become more adjustable. For this reason, there will be a greater need for energy storage and demand-side management in the future.

Main grid planning process

Main grid planning is a continuous process for which Fingrid collects initial data from different sources. By analysing grid sufficiency against this data, it is possible to determine how the main grid can fulfil its purpose as the backbone of the Finnish electricity system in the future. Main grid planning is a complex task due to the geographic extent of the planned grid. The Finnish main grid consists of approximately 14,000 kilometres of transmission lines and 118 substations, which connect grids in neighbouring countries and production plants and major consumption sites located in different parts of Finland to the main grid.

Main grid planning can be divided into three parts: planning of the main power transmission grid, planning of the regional grid, and planning of connections. However, the main grid naturally needs to be planned as a whole, and the division presented above is only intended as a guideline. In particular, as connection capacities rise, connection planning will increasingly give rise to a need to assess the adequacy of the grid more broadly. The main power transmission grid consists of 400 kV and 220 kV transmission lines and makes it possible to connect large power plants and generation clusters to the grid, serves the power transmission needs between countries and regions, and connects the transformer substations that feed the 110 kV main grid and high-voltage distribution networks to the power system. The needs of the electricity market determine the transmission needs between countries and regions, which means that modelling the cross-border electricity market is an important tool in the planning of the main power transmission grid. More technical regional network planning is carried out in cooperation with the customers in 12 planning areas. At the same time, regional needs are matched with the development needs of the main power transmission grid. However, the interfaces are planned in a bilateral manner with customers, taking into account larger network plans and the forecasted development of network transmission capacity. The starting points in the grid development process are electricity consumption and production forecasts and the condition of the grid. A central role in the grid development process is played by the confidential dialogue between Fingrid and its customers, which involves discussing the effects of customers' plans on the main grid. In the present operating environment, it will no longer be possible to carry out planning of the main power transmission grid, the regional grid, and connections in isolation; the requirements of each perspective must be taken into consideration when planning the overall entity. At the moment, a lot of large connections are planned. For this reason, connectivity assessments require extensive analysis at many levels, including assessments of the main electricity transmission grid.

International cooperation on network planning is currently underway at various levels. Fingrid is a member of the European Network of Transmission System Operators for Electricity (ENTSO-E), which creates a 10-year development plan for the pan-European transmission grid every two years. ENTSO-E performs grid planning at both a pan-European level and in regional planning groups; Fingrid is a member of the Baltic Sea regional group. Each regional planning group also publishes a regional grid development plan that focuses on cross-border transmission capacity and the development of connections between price areas. In addition, a Nordic grid plan that focuses on the challenges of the Nordic synchronous area will also be compiled. The national development plan must be consistent with these international plans.

Development plan

In recent years, Fingrid's investments have focused on the domestic network, and a record number of investments have been underway throughout Finland. Over the next 10 years, Fingrid will invest EUR 2.1 billion in the main grid, which is about EUR 200 million per year. Fingrid's annual depreciation amounts to approximately EUR 100 million. Over the next 10 years, Fingrid's main grid investments will involve developing cross-border connections and Finland's internal main power transmission grid, grid connections for new production, and the renewal and refurbishment of the existing grid. The main grid does not have a maintenance backlog, and the grid has been renewed according to the plan and as needed.

Fingrid seeks to cost-effectively secure reliable electricity for customers and society and shape the clean, market-oriented power system of the future. A special goal of the network investments undertaken in the 2020s is to create the conditions for Finland to become carbon neutral by 2035. This carbon-neutrality target will necessitate a significant increase in electricity consumption and clean electricity generation. Fingrid is making preparations to enable this by creating opportunities for new forms of electricity generation and consumption to be connected to the grid and for electricity to be transmitted within Finland and via cross-border connections to Finland's neighbours. In order to respond to rapidly changing needs, Fingrid maintains a flexible, long-term investment plan, which aims to enable electricity markets to operate in the future. The plan facilitates flexible responses to various changes in the operating environment.

In the future, the greatest need for development will be in increasing the transmission capacity between centres of generation and consumption. The most pressing need is an increase in transmission capacity between the north and the south, but transmission from the west coast to the south is also on the rise. As the electricity production of the combined heat and power plants in Southern Finland decreases and the consumption of electricity increases, the deficit in Southern Finland is increasing. This deficit will be offset by wind power from the north and the west, and imports, especially from Northern Sweden. This will cause a major increase in transmission from Northern Finland and the west coast to Southern Finland.

The main grid development plan offers the best current insight into Fingrid's future grid reinforcements. Fingrid updates its plan as a continuous process, in accordance with the changing operating environment. The development plan contains some uncertainty related to new consumption and the connection of new power plants to the grid. In addition, the operating environment also contains major uncertainties associated with the energy revolution and the speed of change in the structure of electricity production, among other things. For example, the amount and geographical positioning of wind power, as well as the speed of electrification of society, have a particularly significant impact on the need and timing of Fingrid's investments. Fingrid is cooperating closely with customers and preparing for possible new connections. Investments in the grid are made at the right time, when the needs are met, enabling Finland to reach its climate-neutrality target.

Introduction

Development of the main grid is one of the basic tasks of Fingrid Oyj, the company responsible for the electricity system in Finland. Long-term development of the main grid ensures that the electricity transmission grid and the entire electricity system meet the requirements set for them now and in the future. The main grid is subject to legal obligations related to connectivity, system security, and the functioning of the electricity market, and these obligations must always be fulfilled. For this reason, the grid is proactively developed as an overall entity to meet the needs of customers and society. The grid needs to be reinforced whenever there are new connections, if customers' connections change in capacity or the power transmitted through the connections changes, and when changes in our neighbouring countries affect the main grid's transmission requirements. At the same time, we must also take care to ensure that the grid remains in good condition by replacing components as necessary, keeping in mind that the grid has been built over the course of many decades.

This development plan presents Fingrid's key main grid development measures for the next 10 years. The development plan is based on regional plans compiled in cooperation with electricity transmission customers and the other European transmission system operators. The plan is aligned with the development plan for the Baltic Sea region, as well as the Ten-Year Network Development Plan (TYNDP) covering the entire European Union. The plan is based on various forecasts of the future. The document also discusses Fingrid's process for developing the main grid and the changes in the operating environment that affect the development of the main grid.

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Foreword

Transforming the network vision into a development plan and investment decisions

Fingrid's network vision, which it published in January, illustrates how well the main grid will be able to meet future transmission needs. The vision sets out the key 400 kV grid solutions for 2035 in various generation and consumption scenarios. This main grid development plan defines the grid investments planned for execution in the 2020s, covering all of Finland and the main grid's various voltage levels. The investments that will be made in the coming years are already fairly clear, but uncertainty increases towards the end of the decade, and we will need to monitor and assess whether the investment criteria are met.

Fingrid invests in its grid whenever part of the grid reaches the end of its service life, if a customer needs a new or upgraded grid connection, or when changes in generation and consumption patterns give rise to a significant increase in transmission volumes. In the last of these cases, there is a risk of network faults causing more widespread contagion if the grid is no longer sufficient to withstand individual faults. In practice, we would then be forced to make investments. Ideally, we would first wait for customers to make their investment decisions before we decide whether to reinforce the grid. However, this is not an option in the midst of an energy revolution, as we have received hundreds of connection enquiries of varying scopes. As such, we need to develop the main grid so that we can forecast our customers' future solutions without knowing the order in which they will ultimately bring their plans to fruition as investments. This is because we do not want to become the bottleneck that hinders Finland's progress towards becoming carbon neutral by 2035. For example, it takes almost 10 years to take a new 400 kV from the drawing board to commissioning. In practice, we try to identify the grid reinforcements needed in multiple future outlooks, so the risk of a wasted investment is low.

A good example of a need identified in the network vision work is the increase in the transmission capacity at Cross-section Central Finland, between Northern and Southern Finland. As this need is identified in all the future scenarios, there is no point in waiting around for transmission volumes to increase. Instead, we should prepare to build several new 400 kV transmission lines in the 2020s: the Forest Line, doubling the Lake Line, a connection from Jylkkä to Alajärvi, and doubling the Forest Line. If we do not do this, there will not be enough transmission capacity, and it will be necessary to divide Finland into two separate bidding areas for the purpose of electricity trading. However, Fingrid aims to keep the grid's transmission capacity at a suitable level to cope with the majority of circumstances and to handle the times of peak transmission using other solutions, such as flexible markets. This is a tough challenge, but we intend to succeed.

We recognise that a sufficiently strong main grid is a regional competitive advantage that can attract investments in electricity generation and consumption to a specific area. As such, our investments will not give rise to substantial changes in the unit price of the main grid tariff, as the volumes of billable energy and power will also increase. However, the transmission needs of the future are so large and difficult to predict that we cannot build out the grid everywhere in advance. For example, it is still uncertain whether there will be a significant increase in wind power in the eastern and most northern parts of Finland, so we will need to postpone our decisions until this becomes clear. Moreover, our resources and those of our contractors are not currently sufficient to handle a faster pace of investment. However, this will not stop us from seeking solutions with customers who need connections, enabling the subsequent expansion of the main grid, and serving as part of an overall solution.

We hope this development plan will demonstrate Fingrid's commitment to improving its grid in order to meet the needs of customers and society. The energy revolution means a lot of work for us, but this also motivates and inspires us.

Jussi Jyrinsalo

Jussi Jyrinsalo, Senior Vice President, Grid Services and Planning

Fingrid's 10-year main grid development plan

Development of the main power transmission grid

Fingrid seeks to cost-effectively secure reliable electricity for customers and society and shape the clean, market-oriented power system of the future. A special goal of the network investments undertaken in the 2020s is to create the conditions for Finland to become carbon neutral by 2035. This carbon-neutrality target will necessitate a significant increase in electricity consumption and clean electricity generation. Fingrid is making preparations to enable this by creating opportunities for new forms of electricity generation and consumption to be connected to the grid and for electricity to be transmitted within Finland and via cross-border connections to Finland's neighbours. In order to respond to rapidly changing needs, Fingrid maintains a flexible, long-term investment plan, which aims to enable electricity markets to operate in the future. The plan facilitates flexible responses to various changes in the operating environment.

At this time, the electricity system is undergoing an unprecedented change as the electricity generation structure is rapidly becoming low in emissions and simultaneously more variable according to the weather.

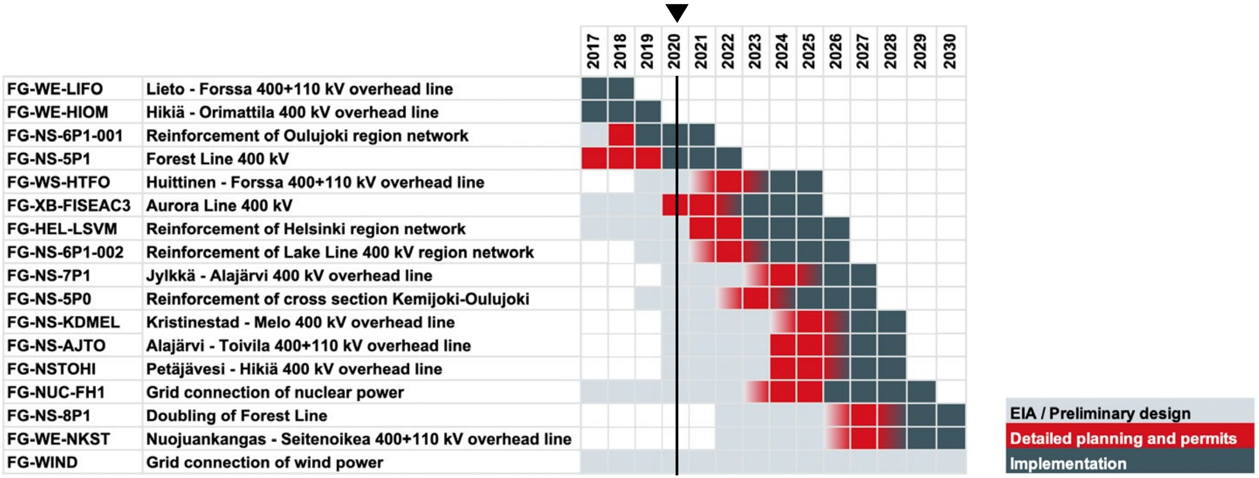


Figure 1. Fingrid's flexible and long-term strategy

The construction of renewable energy for the Baltic Sea region's electricity market has been accelerated by rapid technological development and national subsidy mechanisms. The profitability of conventional generation based on fossil fuels has weakened significantly, which has resulted in a reduction in adjustable generation capacity. This trend will lead to lower carbon dioxide emissions, but it will also call for new types of flexibility, such as demand-side management and energy storage, to prevent increasing the risk of electricity shortages in the system. At the same time, society is becoming more electrified, and electricity dependence is increasing. The electricity system of the future is expected to provide even greater reliability in order to safeguard the vital functions of society.

In the future, the greatest need for development from the perspective of the main power transmission grid will be in increasing the transmission capacity between centres of generation and consumption. The most pressing need is an increase in transmission capacity between the north and the south, but transmission from the west coast to the south is also on the rise. As the electricity production of the combined heat and power plants in Southern Finland decreases and the consumption of electricity increases, the deficit in Southern Finland is increasing. This deficit will be offset by wind power from the north and the west, and imports, especially from Northern Sweden. This will cause a major increase in transmission from Northern Finland and the west coast to Southern Finland.

The north-south transmission capacity is limited by two cross-sections, known as Cross-section Central Finland (P1) and Cross-section Kemi-Oulujoki (P0). The first of these is an electrotechnical boundary that runs across the country from Kokkola in the west via the north side of Iisalmi to the east. The northern region is dominated by hydro and wind power, and there is a surplus of generated electricity. The southern region is dominated by nuclear

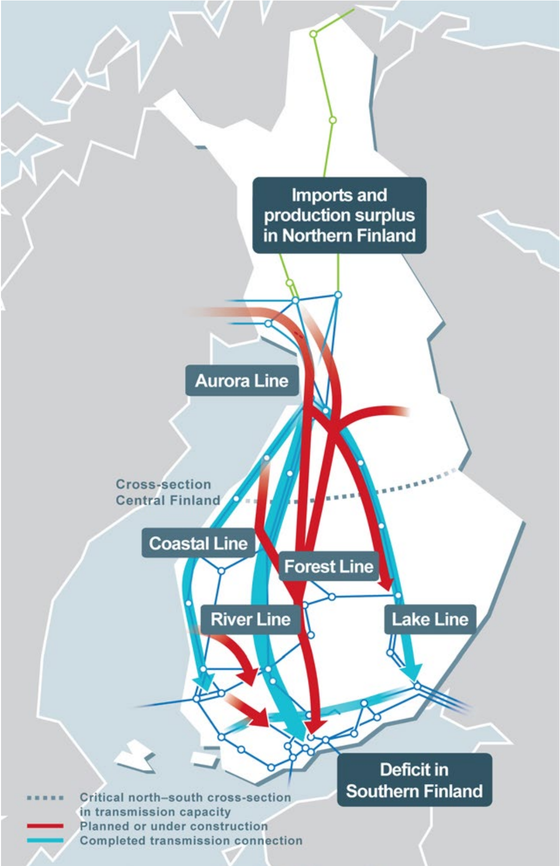


Figure 2. Needs for reinforcing the 400 kV network

and thermal power, and it has a deficit due to the high volumes of consumption. In addition, most of the exported electricity leaves the country via the cross-border connections in the south. Three 400 kV transmission corridors pass through the cross-section from Oulu to the south: the Coastal Line, the River Line, and the Lake Line. Cross-section Kemi-Oulujoki divides the northern region into areas north and south of the River Ii.

The energy revolution has taken place more quickly than expected, and there is a strong concentration of wind power to the north of Cross-section Central Finland, as

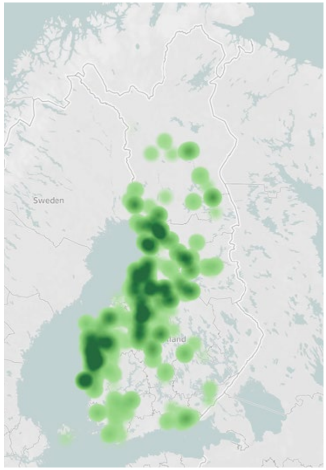


Figure 3. The figure illustrates the locations of public wind power projects in Finland. The darker green areas contain more built and planned wind power.

shown in Figure 3. For this reason, the development plan includes a significant sum in investments to strengthen the north-south transmission capacity. Transmission needs are expected to increase throughout the period reviewed. The following section reviews the development plan for the main power transmission grid. The first section focuses on reinforcements at the cross-sections between the north and the south, and other grid reinforcements are covered thereafter.

Reinforcements at Cross-section Central Finland (P1)

The first reinforcement to Cross-section Central Finland – the new 400 kV Forest Line transmission line (FG-NS-5P1) – will be completed in 2022. The third connection to Sweden – the Aurora Line – will be completed in 2025. The new cross-border connection will increase Finland's imports of electricity, taking up almost all of the north-to-south transmission capacity provided by the new Forest Line.

The transmission capacity through Cross-section Central Finland is currently constrained by the quality of the voltage under normal operating conditions at the substations south of the cross-section, as well as post-fault voltage stability. Therefore, building new transmission lines is not the only way to increase the transmission capacity: shunt compensation can also be implemented to improve voltage support. Shunt compensation is a quick, cost-effective, and environmentally-friendly way of increasing the transmission capacity. Shunt compensation will be implemented at several substations by adding capacitors at the 20 kV and 400 kV voltage levels in 2023 and 2024.

When the Forest Line is completed, construction will begin on the next 400 kV connection to Cross-section Central Finland. The doubling of the Lake Line (FG-NS-6P1-002), running south from Nuojuankangas to Huutokoski, will be completed in 2026.

Approximately 1,000 MW of wind power is expected to be built in Finland every year, and the majority of it will be located along the northern parts of the west coast. In particular, a large volume of wind power will be connected to the Jylkkä substation in Kalajoki and the new Valkeus substation, which will be built in Pyhäjoki, with the total estimated at 2,000 MW. Thousands of megawatts of wind power projects are planned and under construction along the 400 kV Coastal Line between Kokkola and Oulu, and the output from these plants must be transmitted to consumption centres in the south. The Coastal Line alone will not have enough capacity to transmit all of the generated electric power. Transmission line arrangements in the Pikkarala and Ulvila region will provide a quick, cost-effective, and environmentally-friendly way of boosting the capacity of the Coastal Line. The transmission lines will be rearranged in 2023. The new Jylkkä–Alajärvi–Toivila transmission line connection (FG-NS-7P1, FG-NS-AJTO) will also be needed to increase the electricity transmission capacity and reinforce Cross-section Central Finland. The connection will be fully completed in 2028. The Jylkkä–Alajärvi section is being designed with two transmission lines because the number and placement of future power generation projects is difficult to predict. The aim of this plan is to ensure that wind power can be connected to the grid in the future.

Towards the end of the planning period, it will be necessary to implement the Forest Line 2 connection (FG-NS-8P1). At present, a plan is being drawn up to determine the terminal points of the connection and the transmission line route.

The transmission lines to Cross-section Central Finland must be extended from the latitude of Jyväskylä towards consumption centres in the south. In 2028, the Forest Line will be extended from Toivila to Hikiä (FG-NS-7P2). The connection is planned with two transmission lines, and it will be constructed in place of the old 220 kV structural transmission lines.

A large amount of wind power is being built at the southern end of the Coastal Line – to the south of the Jylkkä substation – and the electricity these plants will generate must be transmitted towards consumers in the south. The Coastal Line alone will not have enough capacity to transmit all of the generated electric power. In order to raise the capacity, previous assessments identified the need for a connection from Kristinestad to Melo via Honkajoki (FG-NS-KDMEL) in 2028. A more detailed grid solution for the area is currently in the planning stage. The solution will also seek to improve the grid in the Melo area, enable the connection of wind power projects to the north of Melo, and transmit the wind power output from the west coast towards consumption centres in the south. More detailed plans will be made in 2021.

Reinforcements at Cross-section Kemi-Oulujoki (P0)
The load capacity of transmission lines is strongly dependent on the environmental conditions, chiefly the prevailing temperature and the wind speed. By determining the actual load capacity of a transmission line, the line capacity can be increased by adding connections in which the limiting factor is the thermal load capacity. This technique is known as Dynamic Line Rating (DLR), and it will be deployed on the transmission lines at Cross-section

A special goal of the network investments undertaken in the 2020s is to create the conditions for Finland to become carbon neutral by 2035.

Kemi-Oulujoki. The technique is a quick, cost-effective, and environmentally-friendly way of increasing the transmission capacity at the cross-section.

Cross-section Kemi-Oulujoki will be strengthened by the third cross-border line to Sweden (FG-XB-FISEAC3), which will be constructed in 2024, as the cross-border line will extend to the Pyhänselkä substation. At present, Fingrid expects a large quantity of wind power to be realised north of the River Ii in the next 10 years. Connecting wind power to the grid requires additional strengthening in Cross-section Kemi-Oulujoki (FG-NS-5P0). A transmission line from Petäjäskoski to Nuojuankangas will be completed in 2027, after the Forest Line is doubled.

Other plans to strengthen the main power transmission grid

The aged Oulujoki 220 kV grid will be renewed in stages with a 400 and 110 kV grid. The first phase (FG-NS-6P1-001) will be implemented from 2019 to 2023. The project consists of the construction of a new 400 + 110 kV transmission line from Pyhänselkä to Nuojuankangas and three substation projects. Replacing the 220 kV grid with a 110 kV voltage will reduce maintenance costs and improve system security. In addition, the 110 kV network will provide customers in the area with better service, as it enables easier connections to the main grid, among other benefits. The 220 kV voltage level will no longer be used at Oulujoki as of 2030, when the 220 kV Nuojua–Seitenoikea transmission line is replaced by 400 kV and 110 kV transmission lines.

The new 400 kV transmission line connection between Huittinen and Forssa (FG-WS-HTFO) will improve energy efficiency and system security significantly. The new transmission line connection will enable better maintenance and fault outages without degrading the security of the power system. The Huittinen–Forssa transmission line will ensure and maintain a high standard of system security in the main grid. The general planning of the line has begun, and the new transmission line will be completed in 2025.

Fingrid is prepared to connect wind power (FG-WIND) and the Hanhikivi 1 nuclear power plant (FG-NUC-FH1) to the main grid. The EIA procedure for transmission lines needed for connecting the Hanhikivi 1 nuclear power plant to the main grid ended in October 2016. Fingrid will make decisions concerning the further planning and construction of the grid reinforcements needed to connect Hanhikivi to the main grid in accordance with the progress of the nuclear power plant project. A significant amount of wind power will be built in Finland in the coming years. Fingrid cooperates closely with wind power actors and distribution network companies to ensure that wind power parks are connected to the grid on time. Connectivity will be improved with the construction of new substations, among other things. Fingrid is examining several new locations that would be suitable for transformer substation sites. The aim is to place the new substations in locations that are central to wind power. This will achieve the best solution technically and environmentally. The first of these substations are already under construction.

In the capital region, electricity consumption is increasing while electricity generation is declining. To ensure the supply of electricity for functions important to society and the residents in the region, Fingrid is preparing a 400 kV cable link from the Länsisalmi substation to the Vanhakaupunki substation in Viikki (FG-HEL-LSVM). According to the current consumption projections, the 400 kV cable will be needed only after the ten-year review period is over. Due to the City of Helsinki's land-use plans, the plans allow for expedited implementation. The cable is currently scheduled for construction in 2026, and this will enable Helsinki's western boulevard city to be built around the Vihdintie road, when the 110 kV transmission lines along Vihdintie are replaced by cables.

A glimpse beyond 2030

The need for further reinforcement of the main power transmission grid is expected to continue into the 2030s. In its network vision, completed in January 2021, Fingrid estimated that the need for electricity transmission within Finland would continue to increase as generation and consumption increase further. Especially if Finland becomes an exporter of electricity or fuels refined using electricity, the transmission requirements could become very large. As such, it is worth examining a wider range of solutions than the technologies currently in use (400 kV single-circuit lines, series and parallel compensation). The network vision is available in full on Fingrid's website. Some of the scenarios also foresee the need to reinforce the grid in Eastern Finland, depending on the future locations of wind turbines. Fingrid is working in active cooperation with wind power operators and Finland's regional councils to review the development of projects and how they can be connected to the power system.

The identified potential solutions that require further investigation are the wider benefits of Dynamic Line Rating (DLR) technology (covered later in this document), the use of 750 kV lines, dual 400 kV circuits, and new conductors such as 4-Finch conductors. Unifying parallel and series compensation solutions would speed up their implementation. The possible use of HVDC transmission links within Finland would require broader investigation. It is also apt to examine whether it is more economical overall to transmit hydrogen in the form of hydrogen gas or as electricity when the intention is to use hydrogen as the final energy source. The Finnish gas transmission system operator, Gasgrid Finland, was involved in envisioning a pan-European hydrogen network that reaches Finland[1].

In 2022, Fingrid will prepare its system vision, which will examine the improvements required to the electricity grid and the electricity market. The need for grid investments in the 2030s will be studied in more detail when this vision is prepared. In addition, Fingrid and Gasgrid Finland are collaborating on a project that seeks to study potential future trends related to the production and consumption of hydrogen in Finland. This project will involve assessing how a hydrogen network that operates within Finland and enables hydrogen exports could affect the energy transmission system as a whole.

[1] https://gasgrid.fi/2021/04/13/gasgrid-finland-visiomassa-euroopan-laajuista-vetyverkkoa/

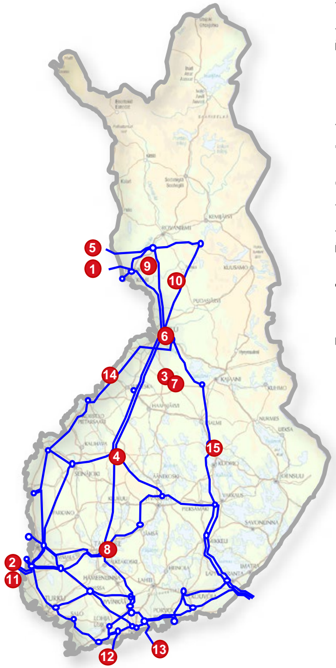
Development of cross-border capacity

The Finnish electricity system is connected to Northern Sweden and Northern Norway via high-voltage alternating current connections and to Central Sweden, Estonia, and Russia via high-voltage direct current transmission links. With the exception of the Norwegian connection, all the aforementioned transmission connections are used by the electricity markets. In early 2021, the commercial maximum transmission capacities of the connections managed by Fingrid and made available to the electricity markets were as follows (From Finland / To Finland).

Sweden: 2300 / 2700 MW
Estonia: 1016 / 1016 MW
Russia 320 / 1300 MW

The actual transmission capacities may be below the maximum transmission capacities due to line outages or the state of grid operation in Finland or its neighbouring countries.

Cross-border capacity has increased strongly over the last 10 years following the implementation of the Fenno-Skan 2 and EstLink 2 submarine cables and the bidirectionality of the Russian connection. Cross-border capacity decreased slightly in 2013 because the transmission power of the Fenno-Skan 1 direct current cable was limited to 400 megawatts due to its maximum voltage.



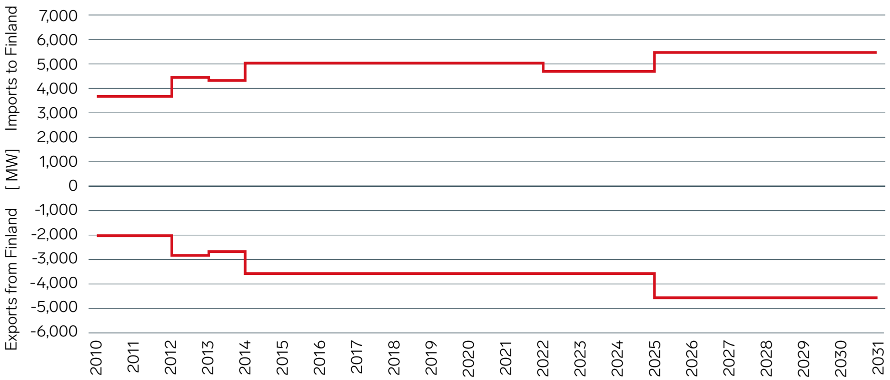


Figure 5. Development of cross-border capacity 2010–2021 and the planned development 2021–2031. The transmission capacities are expressed as maximum commercial transmission capacities (maximum NTC).

1	Series compensation of the transmission links to Sweden	1997
2	Increase of power of the Fenno-Skan HVDC transmission link	1998
3	P1 series compensation	2001
4	Supplements to the Alajärvi switchgear	2003
5	Increase of power of the transmission links to Sweden	2004
6	Renovation of Pikkarala	2004
7	Increasing the level of P1 series compensation	2007
8	Kangasala SVC substation	2008
9	400 kV Keminmaa–Petäjäskoski link and modernisation of the Petäjäskoski switchgear	2009
10	Series compensation of the northern transmission connections	2009
11	Fenno-Skan 2	2011
12	Estlink 1 (purchase)	2013
13	Estlink 2	2014
14	Coastal Line	2016
15	Alapitkä shunt compensation	2019

Figure 4. Investments in cross-border lines and the year in which they were commissioned

Sweden

In early 2021, the alternating current capacity between Finland and Sweden was 1,500 MW of imports from Sweden to Finland and 1,100 MW of exports from Finland to Sweden. With the commissioning of the Olkiluoto 3 nuclear power plant unit, the available import capacity via alternating current connections from Northern Sweden to Northern Finland will decrease by 300 megawatts. In addition to the northern alternating current connections, cross-border capacity between Finland and Sweden is maintained by HVDC transmission links between Southern Finland and Central Sweden with a combined capacity of 1,200 MW. Studies indicate that the service life of the Fenno-Skan 1 connection (400 MW), which was commissioned in 1989, can be extended until 2040[2].

In 2016, Fingrid and Svenska kraftnät carried out a study on the development needs of cross-border capacity. The study found that bottleneck situations will be probable in the future as well, which means that there is a need for a new transmission connection. The most significant benefit of a new connection will be to even out the electricity price differences between the countries. Increasing the transmission capacity will also be very important for the system security of the entire Finnish power system, the sufficiency of electricity, and the enhancement of the reserve market. The Finnish and Swedish transmission system operators decided to move forward with the implementation of the third alternating current connection – the Aurora Line (FG-XB-FISEAC3) – in autumn 2016. Detailed technical planning of the project is underway, and the environmental impact assessment (EIA) is complete. The EU has granted the project a Project of Common Interest (PCI) status. Benefits received by projects selected as PCI projects include an accelerated permit process and eligibility to apply for financial assistance from the Connecting Europe Facility (CEF) financial instrument. The EU granted 50% CEF funding for the planning and environmental impact assessment of the third connection line. Fingrid and Svenska kraftnät will also apply for CEF funding for the construction phase.

The Aurora Line will increase the transmission capacity from Sweden to Finland by 800 MW and from Finland to Sweden by 900 MW megawatts, which corresponds to around 30 per cent of the current overall capacity. The plans call for the transmission line to run from Messaure in Sweden via Keminmaa to Pyhänselkä in Finland, spanning a distance of around 400 kilometres. The estimated costs of the project are approximately 250 million euros. The common goal of Fingrid and Svenska kraftnät is to commission the transmission line connection by the end of 2025.

The results of the network vision indicate that it would be beneficial to increase the cross-border transmission capacity to Sweden by 2035 in addition to building the Aurora Line. The alternatives for increasing the capacity include a fourth AC connection between Northern Sweden and Northern Finland, an HVDC transmission link to Kvarken (bidding area SE2), and a new Fenno-Skan connection between Southern Finland and Central Sweden (bidding area SE3). According to the network vision prepared in 2021, all of the above are viable projects. The planning of new transmission connections will continue as part of international cooperation in network planning, but construction would take place in the 2030s, after the period reviewed in the development plan.

Co-financed by the Connecting Europe Facility of the European Union

Figure 6. The route of the Aurora Line in Finland and route options in Sweden.

[2] https://www.fingrid.fi/sivut/ajankohtaista/tiedotteet/2021/suomen-ja-ruotsin-valisen-fenno-skan-1--yhteyden-kayttoa-jatketaan-vuoteen-2040/

Estonia

There are two HVDC transmission links between Finland and Estonia: EstLink 1 and EstLink 2. In its network vision, Fingrid estimated that increasing the transmission capacity between Finland and Estonia would be economically beneficial in 2035 under certain conditions, which are especially related to the small size of the Baltic market area, and electricity trading between the Baltic states and Russia and between the Baltic states and Poland in the future. The planning of new transmission connections will continue as part of international cooperation in network planning, but construction would take place in the 2030s, after the period reviewed in the development plan.

Russia

The renewal of the Vyborg direct current substation would improve the technical preconditions for transmitting electricity between Russia and Finland and would also provide the opportunity for symmetrical transmission capacity between the countries. Since the decision is a political one and the DC substation is located in Russia, Fingrid cannot decide whether to modernise the substation. Instead, Fingrid will continue its interactions with the Russian transmission system organisation and build and maintain the grid on the Finnish side of the border so that cross-border trade is possible. In addition to renewing network assets, more flexible rules would promote trade and be economically beneficial to Finland and Russia.

Norway

Fingrid and Norway's transmission system operator, Statnett, have examined the development of transmission connections between Northern Finland and Northern Norway. The possible need for transmission capacity is associated with the anticipated increase in electricity consumption by industries in Northern Norway and the possibility of exploiting the wind generation potential in the region. One problem in the region is that the Finnmark area is poorly connected to the other parts of Norway's grid. As a result of earlier studies, the most promising option at this stage seems to be to convert the existing AC connection into an HVDC transmission link with a transmission capacity of 100–150 MW by constructing a back-to-back HVDC substation on Norway's side of the border. The conversion could be carried out in the mid-2020s. Changing the connection technology from a high-voltage alternating current connection to a high-voltage direct current transmission link would enable better control of the bottlenecks in the surrounding grid and mitigation of the stability problems that restrict transmission. At the same time, Statnett intends to strengthen its own grid in Northern Norway in phases towards the Finnish border.

The studies also examined the construction of a 400 kV alternating current line between the countries. Based on the analyses carried out in the Nordic network plan, this would not be a feasible solution from a technical or market point of view. For reasons of voltage and stability, the capacity of the connection would remain low, the amount of electricity

transmitted would be difficult to bring into line with the solution offered by the power exchange, and the risk of internal bottlenecks in Northern Norway would increase. As Fingrid sees it, resolving these problems would require a significant strengthening of the network in Norway and also in Finland, where the network would need to be strengthened all the way from Northern Lapland to Southern Finland. In addition to network strengthening, network solutions would also be needed to direct the flow of power as desired between Northern Norway and Finland. These could include, for example, a larger back-to-back link between Finland and Norway, a longer HVDC transmission link between Finland and Norway, one or more phase-inverting transformers, or adjustable series compensation installations. Due to the long distances, such a solution would probably be very costly.

Development of the regional grid

The regional development plans for the main grid are set out in the following sections. There are 12 regions divided on geographical and electrotechnical bases. The sections examine the special features, investments in recent years, and the development plan for the main grid by planning area. The plans are shown on a map at the end of each section. On the maps, Fingrid's 400 kV transmission lines are shown in blue, 220 kV transmission lines are shown in green and 110 kV transmission lines are marked in red. Transmission lines owned by other companies are shown in black.

The key target in Fingrid's main grid development plan is flexibility. The main grid development plan will be updated every second year and represents Fingrid's prevailing plan for the development of the grid. Fingrid also has an investment plan, which is updated as part of a continuous process in accordance with the changing operating environment. The information on planned projects is preliminary and will become more specific as the date of implementation draws closer. The final method of implementation and the schedule will be clarified in connection with an investment decision. This approach has proven successful, as Fingrid is able to react quickly if it needs to make changes to the grid due to changes in the operating environment. In particular, the large number of wind power projects and the associated uncertainties could cause the situation to change rapidly. Moreover, new tools have been introduced in recent years, such as reports and dynamic maps, to improve shared situational awareness, and this has made decision-making more flexible and effective.

The main grid development plan and its scheduling are affected by many factors, including

- The needs of Fingrid's existing customers and possible future customers
- Changes in the electricity market, whether in Finland
  or in its neighbouring countries
- Changes in energy policy, whether in Finland or in its neighbouring countries
- The condition of the grid
- The possibility of organising any transmission outages required by the project

- The resources of Fingrid and its service providers
- Environmental procedures and permits required in relation to land use and the environment.

As a result of route planning and the related environmental reports or environmental impact assessments (EIA), the line routes presented in the main grid development plan will be revised as planning progresses. Based on the clarified route and substation location plans, Fingrid will prepare for the new land use needs as required by the electricity transmission grid.

Lapland planning area

Description of the area

The Lapland planning area encompasses over one-quarter of Finland's surface area but is home to only approximately 150,000 residents. The largest electricity consumers in the area are mines, downhill skiing centres, and large population centres. Approximately 800 MW of the hydro power along the Kemijoki river is located in this planning area. During flooding season, typically in May, the hydro power plants produce electricity at full power, while at other times, hydropower can be adjusted according to the market situation. There is a cross-border transmission connection from the area to Varangerbotn in Norway. A hydro power plant on the Paatsjoki river on the Russian side of the border is connected to Ivalo. Lapland's 220 kV and 110 kV grid is connected to the 400 kV main power transmission grid by substations in Pirttikoski and Petäjäskoski. The other transformer substations in the area are located in Valajaskoski, Isoniemi, Vajukoski, Kokkosniva, Ivalo, and Utsjoki. Electricity is primarily transmitted in the area using a 220 kV meshed grid. In addition, there is also a 110 kV ring connection between Valajaskoski and Vajukoski.

Recent investments in the Lapland grid

The Lapland grid has seen heavy investments in the last 10 years. The 220 kV Petäjäskoski–Valajaskoski–Isoniemi–Vajukoski ring connection was completed at the start of the decade. In 2015 and 2016, additional transformers were added to both the Pirttikoski and Petäjäskoski 400/220 kV transformer substations, and improvements were made at the substations to boost system security. In addition, the system security of the Vajukoski switchgear in Sodankylä was improved, and another transformer was added to the substation in 2016. The Kuolavaara–Keulakkopää wind farm was connected between Sodankylä and Kittilä. In order to connect the wind farm to the grid, the 220 kV Kuolajärvi substation was built in 2015 along the transmission line between Isoniemi and Vajukoski. An extension to the Isoniemi substation will be completed in 2021, with the addition of a transformer and enhanced system security at the substation.

Development plan for the Lapland region

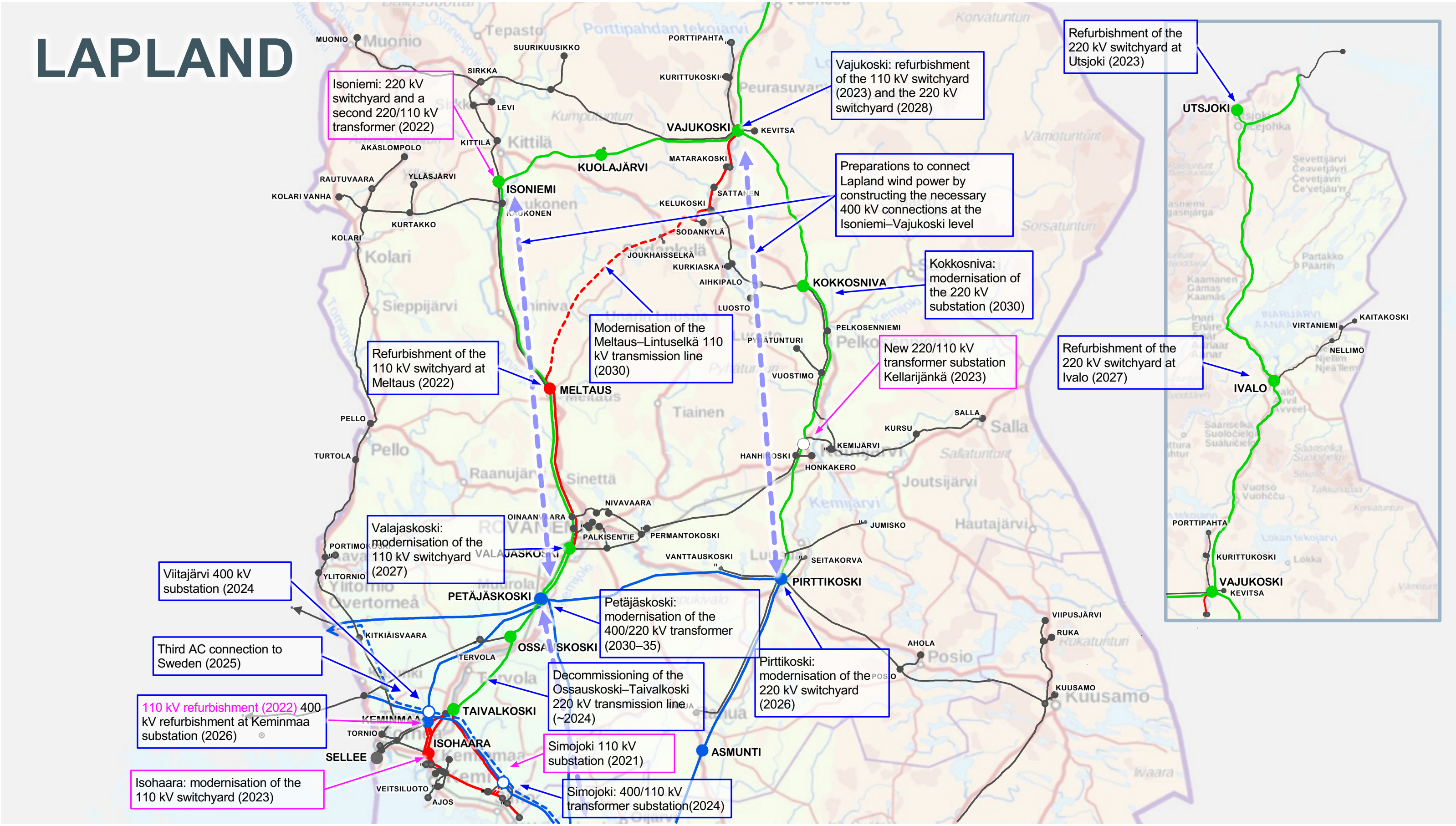
The investments made in the grid in the Lapland region have laid a strong foundation for connecting new forms of generation and consumption to the grid, but the increasing number of wind power projects and growing sizes of turbines require even more expansive plans to develop the network. The plan for these 400 kV development requirements will be revised in 2021, but preparations are initially being made for 400 kV connections from Pirttikoski and Petäjäskoski to the north.

The new Kellarijänkä 220/110 kV substation in Kemijärvi will be completed in 2023, allowing wind power plants to be connected and electricity transmission in the region to be improved. A biorefinery project is also underway in the region, and the substation will enable the plant to be connected to the grid.

The ageing Lapland network will be modernised in the planning period. The Meltaus substation will be refurbished in 2022, and an arc suppression coil will be added. The 220 kV switchgear in Pirttikoski will be modernised in 2026, as will the 110 kV switchgear in Valajaskoski. The 110 kV Meltaus–Lintuselkä transmission line will be modernised in 2030. Refurbishments and modernisations will also be performed at some of the substations in the area. At the end of the decade, the substations in Valajaskoski, Ivalo, Utsjoki, and Kokkosniva will be modernised or refurbished.

Some of the 220/110 kV transformers and the related 110 kV substations in the Lapland region are owned by Fingrid, and some are owned by distribution or regional grid companies. Fingrid aims to clarify the ownership of the 220/110 kV transformer substations in Lapland. With regard to transmission lines, the 220 kV Ossauskoski–Taivalkoski transmission line will be decommissioned from the main grid in about 2024.

The responsibilities for 110 kV quenching practices in the Lapland region will be altered, and in the future, Fingrid will be fully responsible for maintaining the quenching capacity. Arc suppression coils will be added in Kellarijänkä and Valajaskoski, in addition to Meltaus.



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The grey colour means that the project is complete

* Implementation depends on a customer project.

Sea Lapland planning area

Description of the area

The Sea Lapland planning area extends to the Iijoki river in the south and Pello in the north. There are fewer than 70,000 residents in the area. Electricity consumption is concentrated around Kemi and Tornio. The largest industrial facilities are the Veitsiluoto paper mill, the Kemi pulp mill, and the steel mill in Röyttä, Tornio. Metsä-Fibre is replacing its Kemi pulp mill with a new bioproduct factory, and when this project is implemented, it will be the largest investment in the history of the Finnish forestry industry. In April, Stora Enso announced the closure of the Veitsiluoto plant in 2021.

The area's electricity generation capacity consists of power plants at industrial facilities, the hydro power plants on the Kemijoki river, and wind power plants. Approximately 350 MW of wind power has already been constructed in Sea Lapland, and the capacity is expected to increase substantially in the future.

The 110 kV electricity transmission grid in Sea Lapland connects to the 400 kV and 220 kV main power transmission grid via the Keminmaa, Isokangas, and Taivalkoski transformer substations. The coastal areas around the Sea of Bothnia are supplied by a 110 kV meshed grid, which connects to the grid in the Oulu region.

Recent investments in the Sea Lapland grid

Wind power generation capacity has already been constructed in Sea Lapland, with plenty more expected in coming years. The main grid was reinforced in 2015, with the construction of a double 110 kV line approximately four kilometres in length between Isohaara and Keminmaa, which will allow for two 110 kV line connections between the Isohaara and Keminmaa substations and the Taivalkoski and Keminmaa substations.

In 2016, the conductors in the 110 kV Isohaara–Raasakka transmission line between Kemi and Iijoki were replaced with conductors with a better transmission capacity. At the Isohaara end, high-temperature conductors were used for the first time in Finland, as they allowed for an increase in transmission capacity using lighter conductors than the conventional ones. Conventional aluminium-conductor steel-reinforced cable was used to replace the conductors in the southern section.

The substations in Taivalkoski, Ossauskoski, and Keminmaa have been refurbished in recent years. The Raasakka substation was modernised in 2019. In addition, the new 110 kV Simojoki substation will be completed in Simo in 2021. The Simojoki substation is being built to enable wind power to be connected and to ease outages in the region.

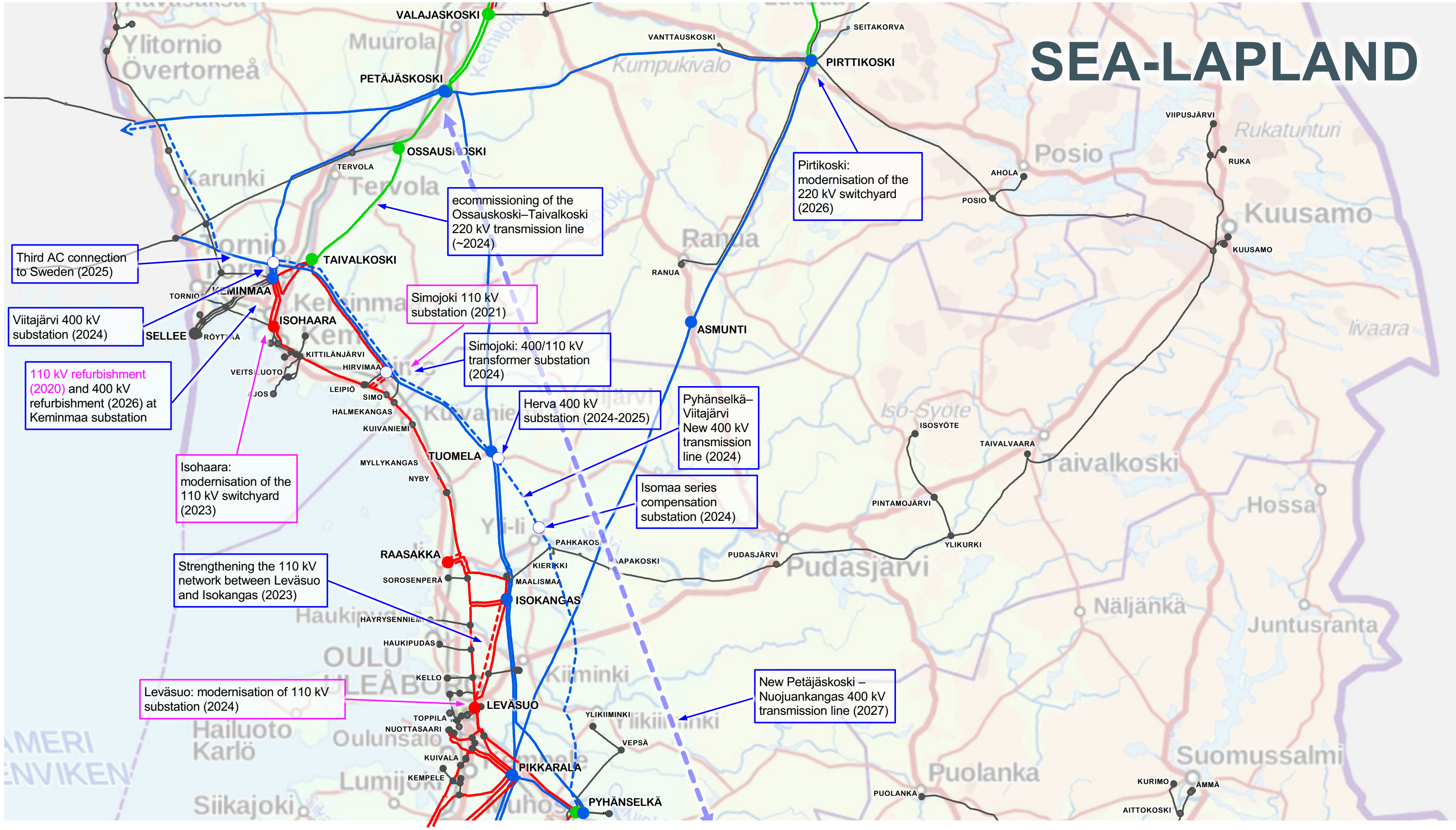
Development plan for Sea Lapland

The 220/110 kV Taivalkoski transformers will be decommissioned by the end of 2025, when the transformers reach the end of their technical life cycles and the main grid has been reinforced by the 400 kV Aurora Line – the third AC connection between Finland and Sweden. At the same time, the 220 kV Ossauskoski–Taivalkoski transmission line will no longer be used in ring operation as part of the main grid. The Aurora Line will join the main grid at the Viitajärvi substation, which will be completed in 2024 in Keminmaa. From here, the 400 kV connection will continue to the Pyhänselkä substation.

The 110 kV Simojoki switchgear will be expanded with the addition of a transformer substation in 2024 to enable wind power to be connected to the grid. There are also plans to build the Herva substation in the vicinity of the Tuomela series capacitor station.

The projected development of wind power north of Cross-section Kemi-Oulujoki calls for further strengthening of the network to the cross-section, and a 400 kV connection from the new Nuojuankangas substation in Vaala to the Petäjäskoski substation is being planned. The need to strengthen the grid manifests itself towards the end of the review period, with the planned completion taking place after the doubling of the Lake Line in 2027. A new 400 kV substation is being planned near the Runkaus nature reserve along the power line.

Refurbishments or modernisations are planned at some of the substations in the region. For example, the 110 kV Isohaara substation will be modernised in 2023, when a few of the connecting towers between Isohaara and Raasakka will also be modernised.



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Oulu region planning area

Description of the area

The Oulu planning area comprises the area between Siikajoki, Muhos, and Iijoki. There are approximately 300,000 residents in the area. The major industrial plants in the area are the Nuottasaari board and pulp mill and SSAB's steel mill in Raahe. The region also has lots of other industries with relatively high electricity consumption. The area's electricity generation capacity comprises power plants that produce district heating in addition to electricity for the city of Oulu, power plants at industrial facilities, the Iijoki and Oulujoki hydro power plants, and wind power. A large amount of wind power is also planned in the area. The 110 kV network in the area connects to the 400 kV main power transmission grid at the Pikkarala, Isokangas, and Pyhänselkä substations.

Recent investments in the Oulu area

Around 10 kilometres of ageing transmission lines near the Raasakka hydro power plant at the mouth of the Iijoki river were renewed in 2015. The 400 kV Coastal Line from the Hirvisuo substation to the Pyhänselkä substation, which was completed in 2016, runs through the Ostrobothnian coastal area. The Coastal Line was built to improve the

transmission capacity between the north and south of the country and allow for efficient electricity market operations. The Coastal Line also improves the transmission reliability rate in the area and creates the conditions for the connection of wind and nuclear power to the main grid.

In 2016, a transformer substation was constructed at Isokangas to the north of Oulu. The new substation will connect the 400 kV and 110 kV grids along the Iijoki river. In addition to the construction of the substation, a nine-kilometre-long 2 x 110 kV transmission line was built from the Leväsuo–Raasakka line to the Isokangas substation. The new Isokangas substation ensures transmission reliability in the Oulu region and allows wind power to connect to the grid in the area.

A large quantity of wind power is planned and under construction to the south of Oulu. In order to connect the wind power to the grid, Fingrid built a new 110 kV substation in Siikajoki in 2016. The Siikajoki substation can also be expanded to become a transformer substation. The old Kalajoki substation was demolished and replaced by the new Jylkkä substation in 2016. The Jylkkä station connects to the Coastal Line, and it is being expanded with the addition of a third transformer, among other actions, to enable wind power to be connected to the grid. The expansion project will be completed in 2022. The 110 kV switchgear in Pikkarala, among the ageing substations in the area, was refurbished in 2020. At the same time, new gas-insulated switchgear was commissioned in Raahe to replace the Rautaruukki substation in the main grid.

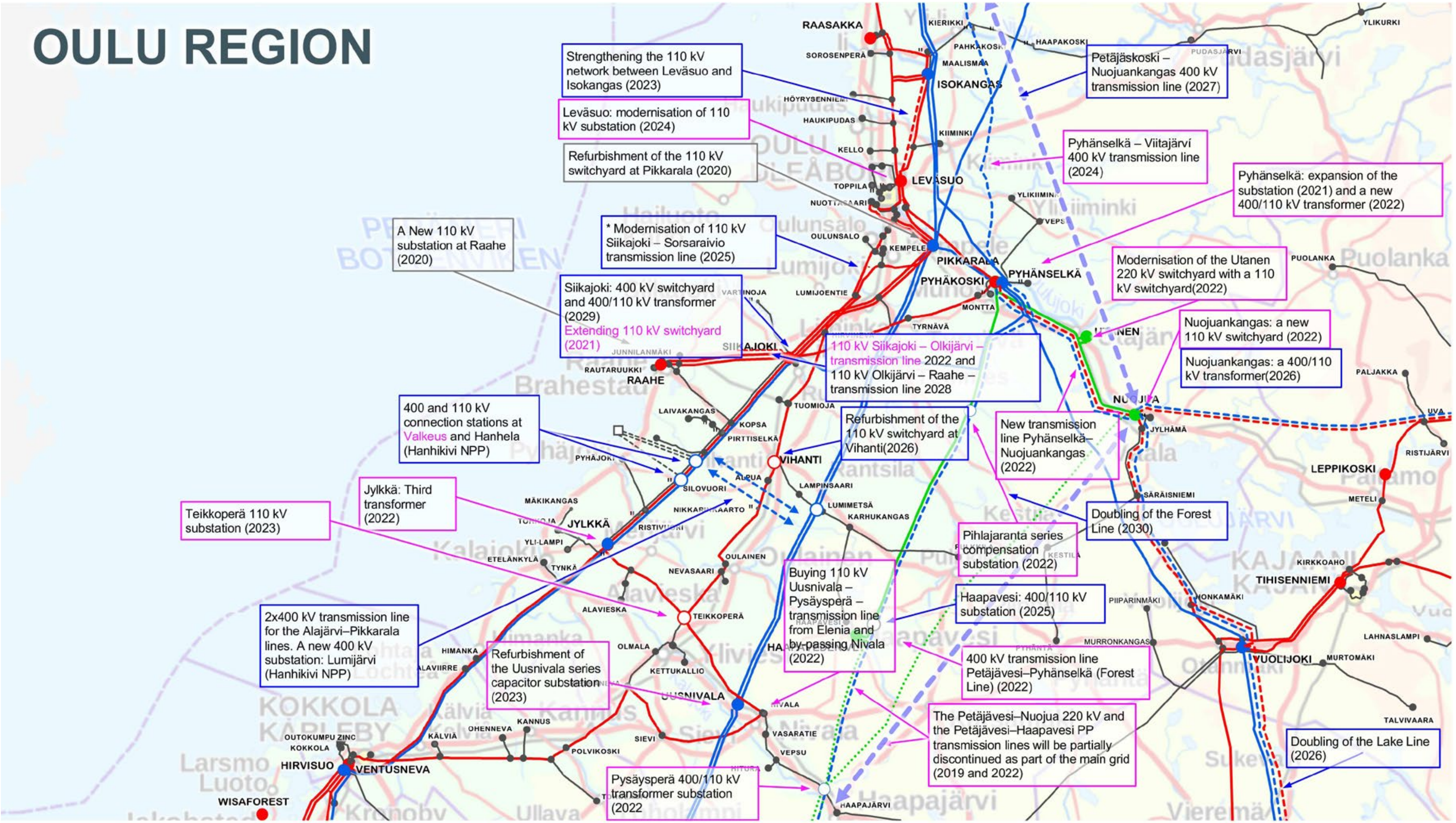
Development plan for the Oulu area

The 110 kV Leväsuo switchgear will be modernised in 2024. At the same time, the 110 kV network between Leväsuo and Isokangas will be strengthened, with the addition of a new transmission line.

The north-south power transmission capacity will be increased in 2022 with the construction of the Forest Line, which is the fifth 400 kV connection through Cross-section Central Finland. Along the Forest Line, the Pysäysperä substation will be completed in Haapajärvi to enable the connection of wind power and improve the system security of the distribution network. The Haapavesi substation is planned for construction along the Forest Line in the Oulu region planning area, to replace the Haapavesi PP substation and enable wind power plants in the area to be connected to the grid.

The third connection to Sweden – the Aurora Line – will be completed in 2025. The connection will pass through the Pyhänselkä and Viitajärvi substations to Sweden and increase the north-south transmission capacity in Cross-section Kemi-Oulujoki. The transmission capacity of the same cross-section will be increased by the planned 400 kV transmission line from Nuojuankangas to Petäjäskoski in 2027.

The 400 kV Hanhela substation and the 110 kV Valkeus substation have been planned to enable the connection of the Hanhikivi 1 nuclear power plant to the grid. The Valkeus station will be designed as a 400/110 kV transformer substation and built in 2023 to enable wind power plants to be connected to the grid. In addition, the 110 kV Teikkoperä substation will also be constructed in 2023 to enable the connection of wind power. Two 400 kV connections from the Hanhela substation to the Lumijärvi substation, which will be constructed along the Alajärvi–Pikkarala transmission line, are being planned to cater for the Hanhikivi nuclear power plant. Fingrid will make decisions on the further planning and construction of the main grid reinforcements required to connect Hanhikivi to the grid in accordance with progress on the nuclear power plant project.



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Kainuu planning area

Description of the area

Electricity consumption in the Kainuu area primarily consists of consumption by services and households. The planning area has a population of approximately 90,000. No population growth is expected, so the growth in load caused by civil consumption is expected to be slow. The area has a few industrial facilities and mines in Talvivaara and in Lahnaslampi, Sotkamo, which are significant with regard to main grid transmission. The Kainuu region currently has an electricity production capacity of over 900 MW. The majority of this is produced in the northern part of the area through hydro power. There is a back-pressure power plant in Kajaani that generates heat for industrial and district heating needs in addition to electricity. In addition, there are plans for several thousand megawatts of wind power in the area, of which approximately 100 MW is in operation, and around 400 MW is under construction or agreed for connection. The Kainuu 110 kV electricity transmission grid connects to the 400 kV and 220 kV main power transmission grid via the Vuolijoki, Nuojua, and Seitenoikea transformer substations. Consumers in the area are supplied with electricity by 110 kV meshed grids, even over long distances.

Recent investments in the Kainuu grid

Since the start of the 21st century, system security in the region has improved significantly thanks to investments in transmission lines and substations. These investments have helped to provide the Kainuu ring network with sufficient transmission capacity, even during transmission and maintenance outages. A reactor from the Ventusneva substation was added to the Nuojua substation in 2017 to support voltages in the area. In the northern sections of the Kainuu planning area, the old Seitenoikea transformer, which had an insufficient load capacity, was replaced with a new transformer with greater load capacity. This will provide enough transmission capacity to connect wind power to the grid. The old Tihisenniemi substation was converted to gas-insulated switchgear in 2019.

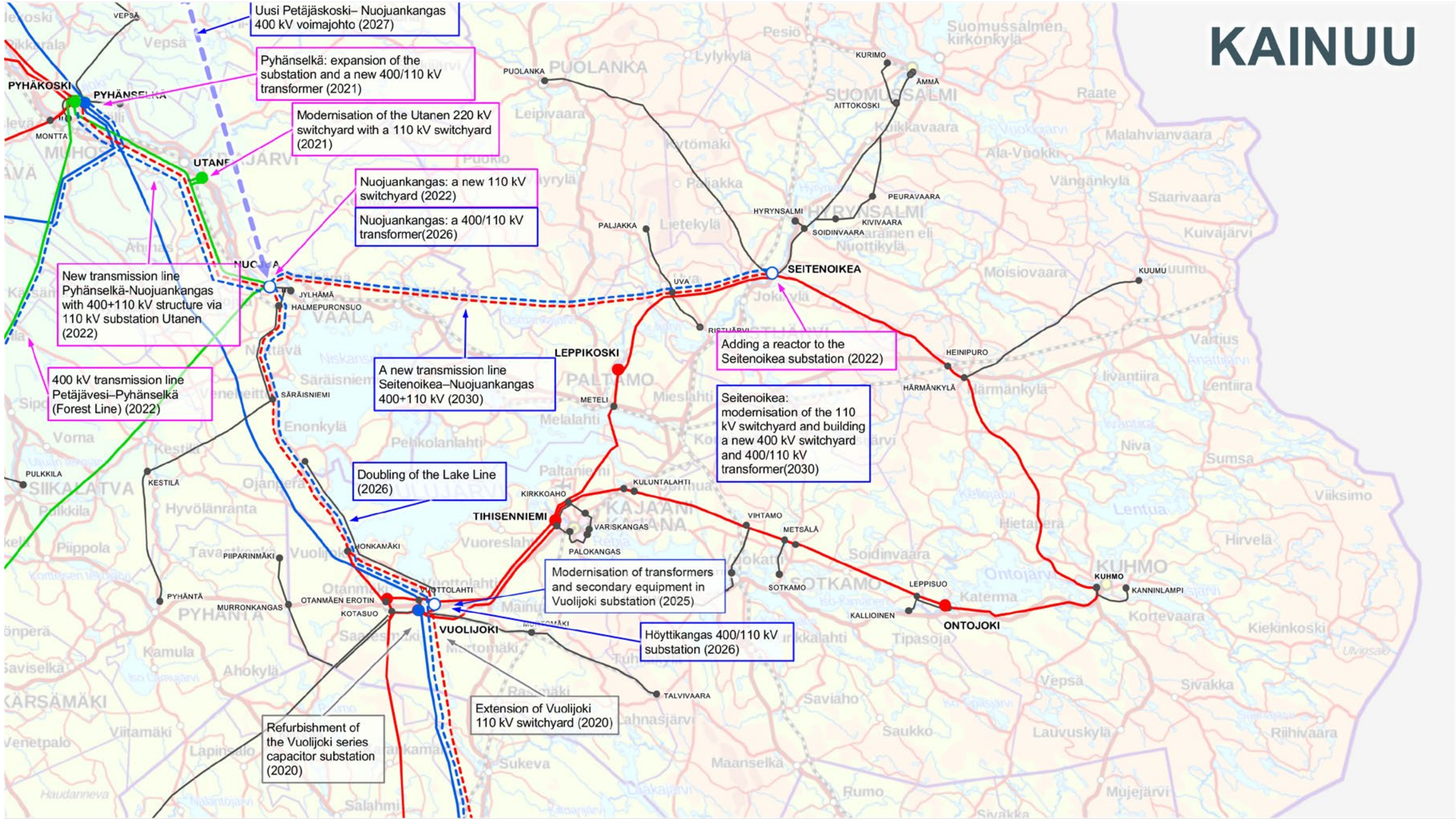
Development plan for the Kainuu region

The ageing 220 kV grid throughout the Kainuu and Oulujoki area will be gradually replaced by a 400 kV and 110 kV grid. Phasing out the 220 kV voltage level will eliminate the need for three switchgear plants and five transformers, resulting in lower maintenance and investment costs. The 110 kV grid will also allow for transmission line connections and simplify voltage control in the area. The replacement of the 220 kV voltage level in the area will start with the construction of a new 400/110 kV transformer and 110 kV switchgear at Pyhäselkä in 2021. At the same time, the switchgear at Utanen and Nuojua will be converted into 110 kV switchgear plants. The Nuojua substation will be modernised in the vicinity of an existing substation, and the new station will be known as Nuojuankangas. A 400 + 110 kV connection will be built between Pyhäselkä and Nuojuankangas in 2022. The connection will initially be operated at 110 kV, and full 400 + 110 kV operation will begin once Lake Line 2 is completed in 2026.

When the reactor at Nuojua substation is decommissioned, a reactor will be added to Seitenoikea in 2022 to help voltage control on the remaining 220 kV grid. The fifth 400 kV north-south connection from Petäjävesi to Pyhänselkä – known as the Forest Line – will be completed in 2022, and the 220 kV network from Petäjävesi to Haapajärvi and from Pysäysperä to Nuojuankangas will no longer be used by the main grid. After the 400 kV connection is completed, the Pyhäkoski substation will be dismantled, except for the 220 kV switchgear, and its main grid operations will be taken over by the adjacent Pyhäselkä substation. The 110 kV Leväsuo and Rautaruukki transmission lines currently running to Pyhäkoski will be taken to Pyhänselkä.

In 2026, a doubling of the Lake Line will be constructed from Nuojuankangas to Huutokoski, to increase Finland's north-south transmission capacity. When the Lake Line is constructed, the Nuojuankangas substation will be expanded, with the addition of 400 kV switchgear and transformers, and a new transformer substation will be built near the Vuolijoki substation to enable wind power to be connected to the grid.

A large number of wind power projects are at the planning stage in the Kainuu region. The large-scale connection of wind power will require 400 kV network solutions, and these are currently at the planning stage. The present plan is to replace the 220 kV Nuojuankangas–Seitenoikea transmission line with a 400 + 110 kV connection. Other investments are also likely to be needed in order to connect wind power, and planning of these is underway. Between the Lake Line and the Forest Line, in the southern parts of North Ostrobothnia, wind power is being planned in enormous volumes in relation to the transmission capacity of the current network. In order to connect these projects to the grid, 400 kV grid reinforcements will be required, and these are currently being planned.



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Ostrobothnia planning area

Description of the area

The Ostrobothnia planning area encompasses the regions of South and Central Ostrobothnia, Ostrobothnia, and some of North Ostrobothnia. The area has a population of approximately 450,000. Electricity consumption is concentrated around the largest cities. Some of the largest electricity consumers in the area are the Kaskinen CTMP plant, the Jakobstad paper and pulp mills and the Kokkola zinc plant. One significant form of electricity consumption in the region, especially in Närpiö and the nearby area, is greenhouse cultivation. The majority of Finland's greenhouse cultivation industry is concentrated in this region. On this scale, the electricity consumption is also significant from the perspective of transmissions in the 110 kV grid. There are back-pressure power plants generating electricity and district heating in Seinäjoki, Vaasa, and Kokkola. The Kristinestad power plant was demolished in 2019, and the Vaskiluoto 3 oil-fired power plant was demolished in 2015. There is relatively little hydro power capacity in this planning area. However, most of the wind power planned for construction in Finland is located on the Ostrobothnian coast. At present, approximately 850 MW of wind power is in operation in the planning area, and 450 MW of wind power is under construction.

Recent investments in the Ostrobothnia grid

The main grid in the Ostrobothnian area has changed a lot over the past 10 years. Previously, the main grid in Ostrobothnia operated mainly at the 220 kV voltage level, but the ageing grid with its insufficient transmission capacity has been modernised in phases. A project entity completed in 2016 involved the construction of a new 400 kV transmission line connection from Pori to Oulujoki. This new north-south transmission line connection is known as the Coastal Line. At the start of the decade, construction was completed on a combined 400 + 110 kV transmission line from Seinäjoki to Tuovila, the Uusniva substation, and a 400 kV transmission line connection from Ulvila to the Kristinestad substation. The last of these was mostly constructed in place of the ageing 220 kV transmission line.

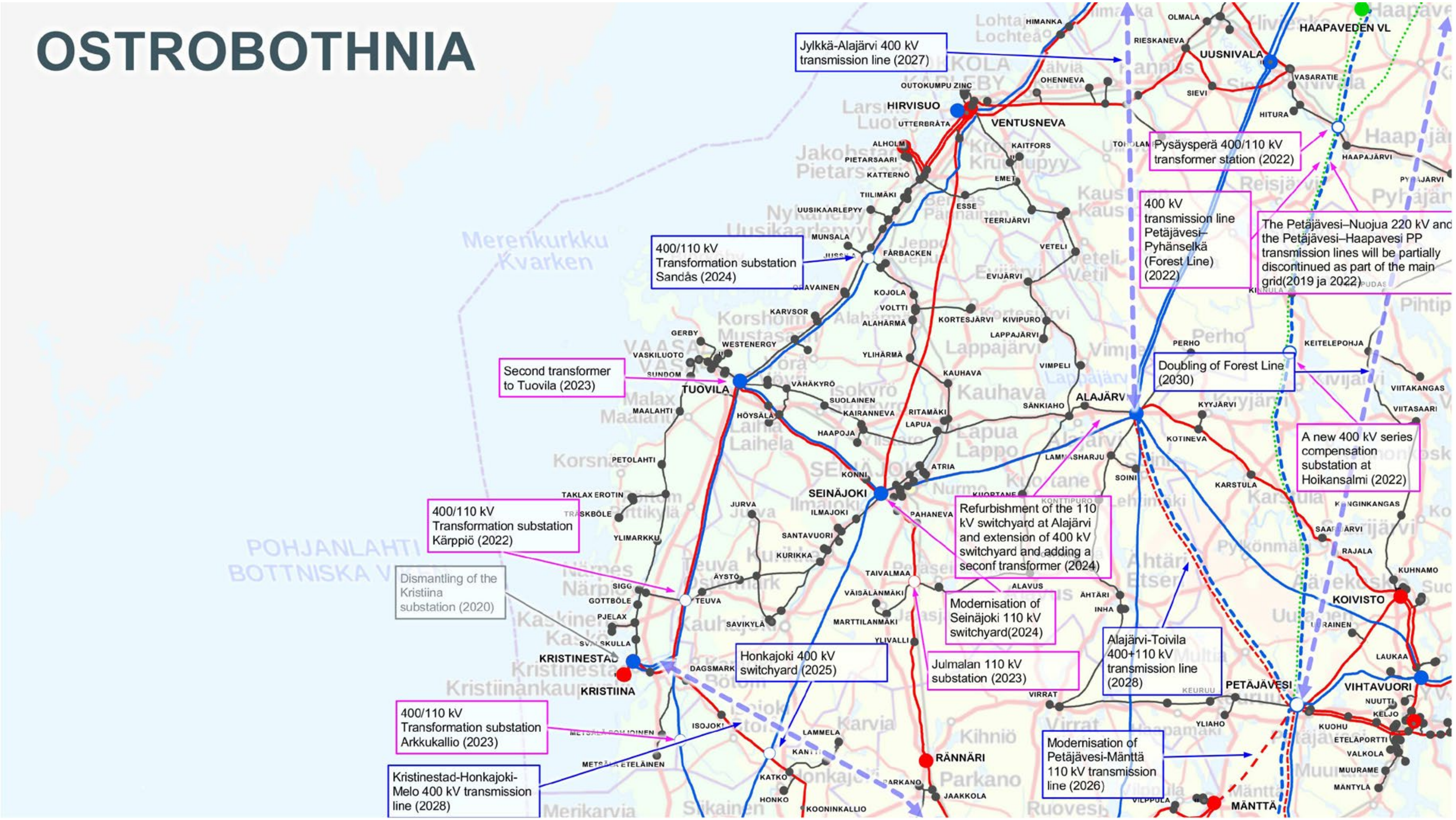
The largest changes took place in 2016. The new Hirvisuo transformer substation in Kokkola was constructed to replace the 220/110 kV transformers at Ventusneva. A second transformer was then added to the station in 2019. A new 400 kV transmission line approximately 210 kilometres in length, from the Hirvisuo substation to Pyhänselkä in the north, was constructed. The transmission line between Kristinestad, Vaasa, and Kokkola has been operated at 220 kV but was built with a structure capable of operating at 400 kV. The line has now been switched to 400 kV operation. The area features a large number of 220 kV structured lines that have not yet reached the end of their service life, so they have been taken into operation at 110 kV.

Development plan for Ostrobothnia

The new grid constructed in Ostrobothnia is sufficiently strong to cover the needs of increasing consumption, and it will be possible to connect large volumes of electricity generation to the grid. A very large number of wind power projects are being planned in the area. Fingrid monitors the progress of wind power projects and investigates potential new sites for substations, to enable wind power generation to be connected.

The Kärppiö transformer substation will be built in 2022, and another transformer will be added to the Toivila substation in 2023 in order to connect new wind power plants to the grid. In addition, the Arkkukallio transformer substation will be built in 2023 to enable wind power connections in the area. Plans are in place to replace the 110 kV Seinäjoki switchgear with gas-insulated switchgear in 2024. A second transformer will also be added in Seinäjoki to enable wind power to be connected. In 2023, the Julmala substation will be built along the 110 kV transmission line between Seinäjoki and Rännäri, to enable wind power connections.

The Sandås substation is planned for 2024, and the Honkajoki substation is planned for 2025. As the amount of wind power between Tuovila and Ulvila is increasing, Fingrid is planning to build a new 400 kV transmission line in 2028 from the Kristinestad area to Honkajoki, from where it can continue to Southern Finland. The Lähteenkylä substation is planned along the new transmission line. A new Jylkkä–Alajärvi–Toivila transmission line connection will also be needed in 2028 to increase the transmission capacity. This connection is being designed with two transmission lines because the number and placement of future power generation projects is difficult to predict. The aim of this plan is to ensure that wind power can be connected to the grid in the future. The scope of construction of this connection will be decided at a later date, once the actual development of wind power projects becomes clear.



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* Implementation depends on a customer project.

Central Finland planning area

Description of the area

One special feature of the Central Finland area is its low volume of electricity generation in relation to its electricity consumption. The planning area has a population of approximately 300,000. Most of the electricity consumed in Central-Finland is transmitted from elsewhere. Major consumers of electricity in the area are large forest industry clusters in the Jämsä river valley, Äänekoski and Mänttä. The structural change in industry in recent years has brought great uncertainty with regard to the development of loads. The Central Finland area has seen development in both directions; some forest industry has been phased out in the area, but decisions have been made to construct more. The closure or expansion of a single large industrial plant can have a wide-reaching impact on transmission in the area's main grid, either reducing or increasing it.

A large share of electricity produced in Central Finland comes from industrial back-pressure plants. In addition, the Rauhalahti and Keljonlahti power plants in Jyväskylä produce electricity and district heating. There are also a few small hydro power plants in the area. Wind power is planned in the area, especially near the Alajärvi substation, with a total output of several thousand megawatts.

The Central Finland area is connected to the 400 kV and 220 kV main power transmission grid through several transformer substations. The area is connected to the 400 kV grid via transformers at Vihtavuori, Toivila and Alajärvi. Central Finland is connected to the 220 kV grid at Petäjävesi and Jämsä. Electricity is transmitted to consumers within the area via 110 kV meshed grids between these transformer substations.

Recent investments in the Central Finland grid

Two substation projects were completed in 2016 in central Finland: the old substation at Mänttä was renewed near the existing substation, and the old 220 kV switchgear at Petäjävesi was renewed with 400 kV equipment and structures. The Petäjävesi switchgear will be taken into operation at 400 kV in 2022. The 110 kV switchgear in Petäjävesi has already been modernised. The renewal of the 400 kV Alajärvi switchgear was completed in 2017, improving the system security of the main grid. When this modernisation took place, the 220 kV switchgear in Alajärvi was demolished as part of Fingrid's plan to phase out the 220 kV voltage level south of Oulujoki by 2022. In connection with the decommissioning, the 220 kV Alajärvi–Petäjävesi and Alajärvi–Seinäjoki transmission lines switched to an operating voltage of 110 kV. At this time, the 220 kV grid remains between the Jämsä, Petäjävesi, Nuojua and Pyhänselkä substations. The transmission capacity and system security of the 110 kV main grid between Koivisto and Vihtavuori was improved by constructing another connection in 2018. The changes were caused by the commissioning of a new bioproduct mill.

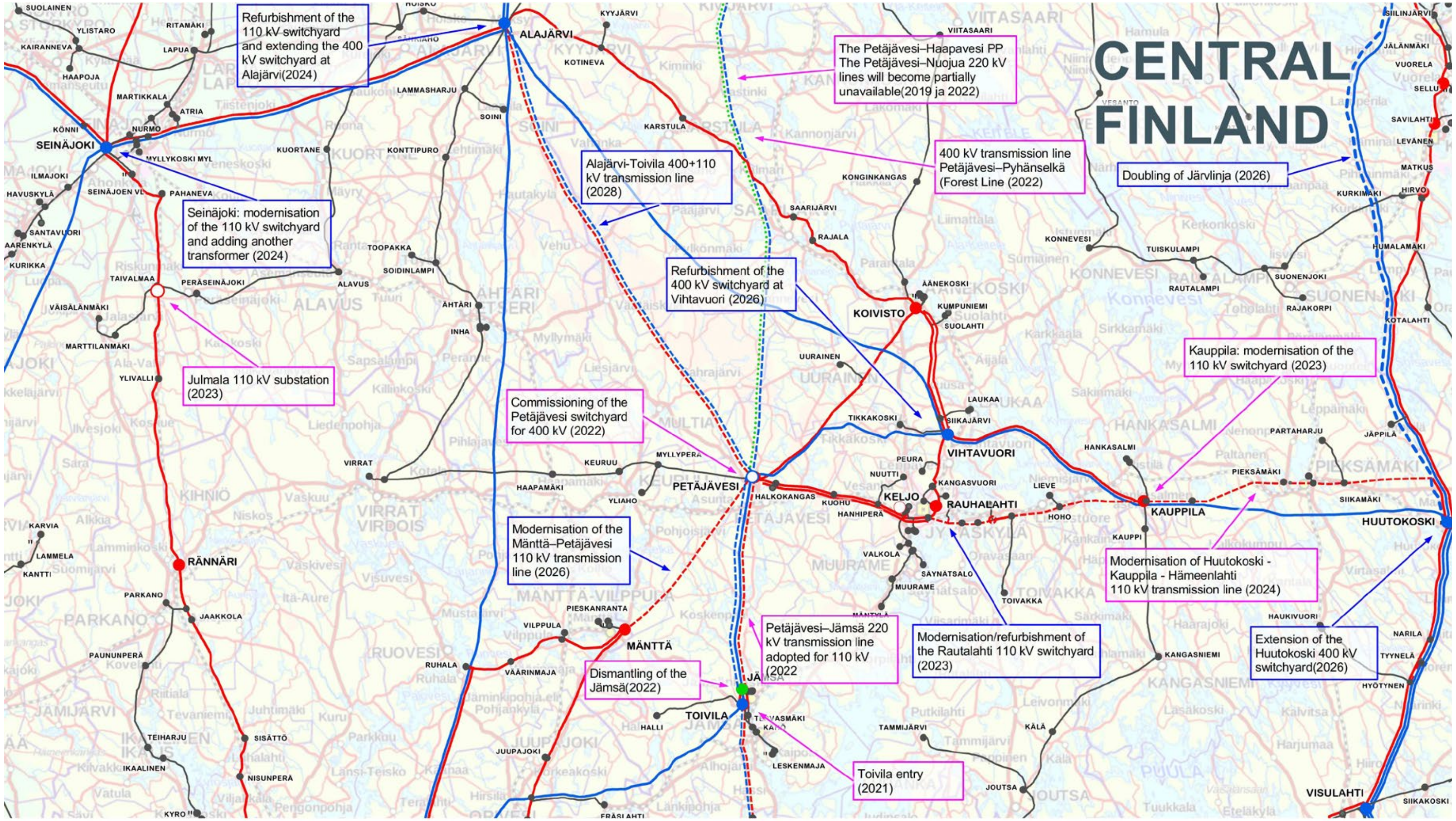
The new 110 kV Jyväskylä substation was built as a gas-insulated switchgear plant, replacing the ageing Keljo switchgear as a hub in the main grid. The Jyväskylä substation was commissioned in 2019. When the substation was built, transmission line connections were made from the Jyväskylä substation to Petäjävesi, Kauppila, and Rauhalahti.

Development plan for Central Finland

The new cross-border transmission line from Northern Sweden (the Aurora Line), scheduled for completion in 2025, and the growing volume of electricity generation in Northern Finland, will increase the transmission need inside the country from north to south (Cross-section Central Finland). In the near future, the need for north-south transmission capacity will also rise when the largest generation unit – Olkiluoto 3 – is connected to the grid. To increase the capacity, the construction of the Forest Line, a new connection from Oulujoki to Central Finland, began in 2019 for completion in 2022. The 220 kV

connections from Oulujoki to Petäjävesi and Jämsä will be phased out at the same time. According to the long-term plan, the Jämsä substation will be phased out once the 220 kV voltage level is no longer in use. After this, main grid operation will be centralised at the Toivila substation in Jämsä, approximately three kilometres away. The 400 kV voltage will be taken into operation at the 220 kV switchgear in Petäjävesi. The 220 kV transmission line between Jämsä and Petäjävesi will be operated at 110 kV, and a 400 + 110 kV transmission line is planned for construction between Alajärvi and Toivila in 2028.

Central Finland has a large number of ageing 110 kV transmission lines built on wooden towers, and these will be renewed. The Huutokoski–Kauppila–Hämeenlahti transmission line will be renewed in 2024, and the Petäjävesi–Mänttä transmission line will be renewed in 2026. The area also has several substations that will require modernisation or refurbishment over the next 10 years. The Kauppila substation will be renewed in conjunction with a transmission line project in 2023. Renewals/refurbishments will also be carried out at Rauhalahti, Alajärvi, and Vihtavuori during the planning period. In conjunction with the 110 kV modernisation in Alajärvi, a second main transformer will be added to the Alajärvi substation, and wind power in the area will be connected with the construction of a new 400 kV field and 110 kV line fields. Towards the end of the planning period in 2030, the Forest Line will be extended southwards from Toivila to Hikiä.



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Savonia-Karelia planning area

Description of the area

The grid in the Savonia-Karelia area is characterised by long distances. There are large distances between the area's production and consumption clusters. Consumption in the area mainly comprises consumption by services and households, but there are also a few industrial facilities in the region that are significant with regards to main grid transmission. The planning area has a population of approximately 550,000. No population growth is expected, so the growth in service and household consumption is not expected to increase significantly. Electricity production consists of heating plants in towns and cities, industrial CHP plants, and dispersed hydro power plants.

Savonia-Karelia is connected to the 400 kV main power transmission grid via 400/110 kV transformer substations at Alapitkä, Huutokoski and Visulahti. Electricity is transmitted within Northern Savonia from the Alapitkä transformer substation via the surrounding 110 kV meshed grid. The Alapitkä substation also supplies the 110 kV grid, which is in radial use by the distribution network. Northern Karelia is fed by the Alapitkä and Huutokoski transformer substations and the four long 110 kV ring connections. In addition, there is one 110 kV main grid connection that runs from the direction of Kitee in the south. Southern Savonia is fed by a 110 kV meshed grid from the Huutokoski and Visulahti transformer substations.

Recent investments in the Savonia-Karelia grid

Transmission line and substation investments have been made in the area to improve the transmission capacity and system security. The 110 kV Varkaus–Kontiolahti transmission line was completed in spring 2015. The new transmission line connection replaces the old transmission line, which has low transmission capacity. The transmission line provides Northern Karelia with additional transmission capacity and simultaneously improves the system security of the electricity grid in the area.

During 2016, two aging main grid substations were renewed in the area: The old substation in Varkaus was renewed in order to guarantee good system security for the area in the future and the new Kiikanlahti substation was built in Kitee. The Kiikanlahti substation replaces the old Puhos substation. In association with the construction of the Kiikanlahti substation, a conductor replacement along the Kiikanlahti-Suursuo section of line was also carried out. An increase in the load capacity of the section of line supports the main grid in the area in the event of outages along the lines that feed Northern Karelia. In addition, it also allows for the more efficient use of the Kiikanlahti-Pamilo transmission line. The Huutokoski 110 kV switchyard was modernised into a GIS switchyard in 2018. A new 110 kV switchyard was completed in the same year in Iisalmi, replacing a customer's Peltomäki switchyard as a main grid hub. A refurbishment project was completed in the Alapitkä station in 2019. As part of the refurbishment, a 400 kV capacitor was added to Alapitkä to support the voltage and increase the north-south transmission capacity. A capacitor was added to the Uimaharju substation in 2019 to support the voltages in the North Karelia area. The project to refurbish and expand the Kontiolahti substation was completed in 2020. The substation was expanded with the addition of two power lines and a second main busbar.

Development plan for the Savonia-Karelia area

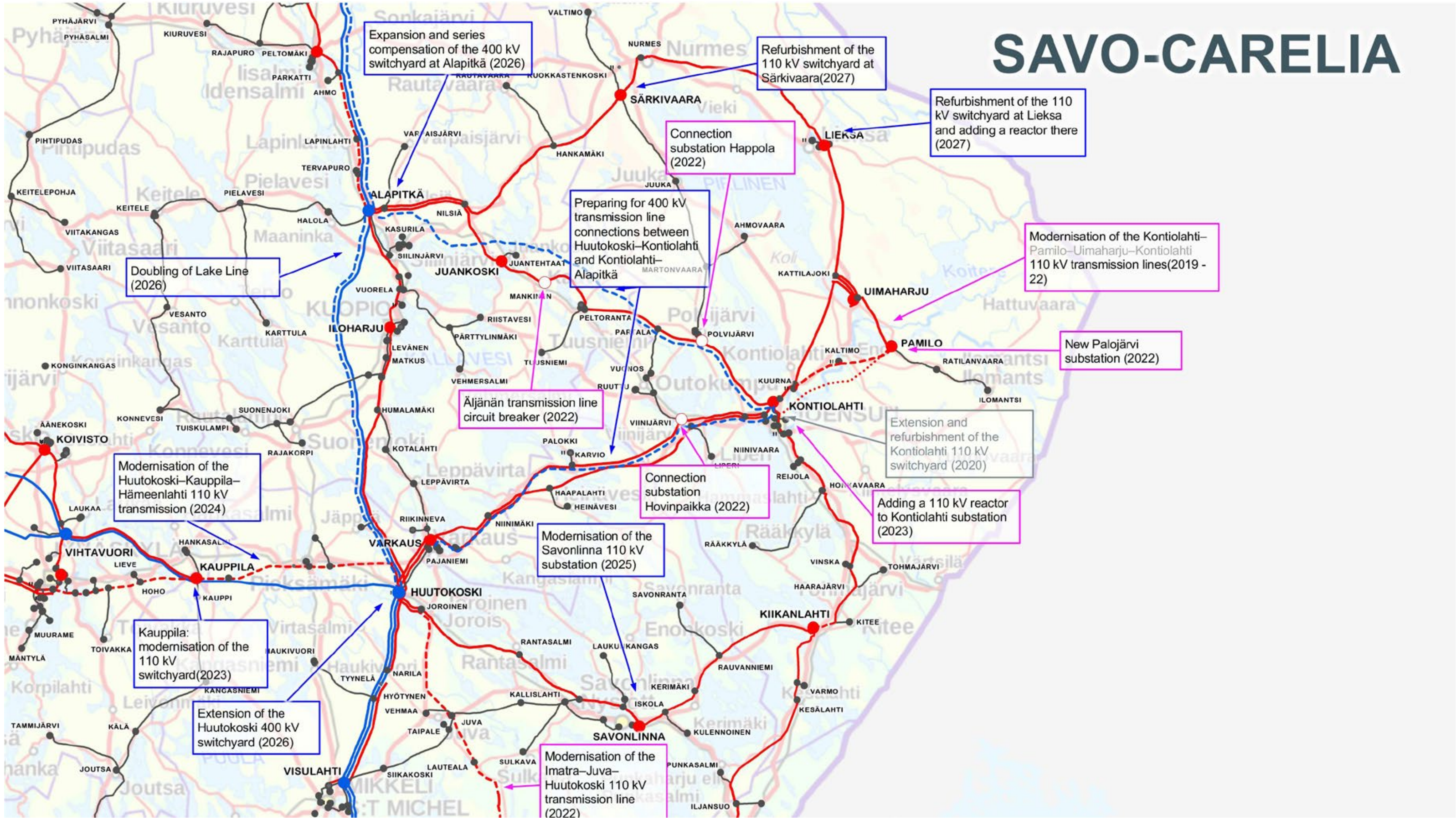
There is currently no need to carry out significant reinforcements to increase the main grid's transmission capacity in the Savonia-Karelia area. Investments over the next 10 years will mainly be due to the ageing grid. However, it should be noted that new development needs may arise at short notice due to the nature of the transformation underway in the energy sector.

North Karelia has a large number of ageing 110 kV transmission lines on wooden towers. The modernisation of these towers is underway and will continue. The Kontiolahti–Uimaharju–Pamilo project entity is currently under construction. The entity includes the renewal of the 110 kV Kontiolahti–Uimaharju, Uimaharju–Pamilo, and Pamilo–Kaltimo–Kontiolahti transmission lines between the substations. In conjunction with this modernisation, the Pamilo substation will be replaced by the new Palojärvi substation. Some of the new transmission lines are already in operation, and the remainder will be commissioned in 2022. Once the project entity has been completed, the 110 kV Kiikanlahti–Pamilo transmission line will be taken into Kontiolahti, and the old end, which is in poor condition, will be dismantled.

In spring 2021, the decision was made to invest in a reactor to be installed in Kontiolahti in 2023, to ease the occasional voltage problems in the area. Several main grid substations in the Savonia-Karelia planning area have undergone renewal and refurbishment in recent years, and many other projects are being planned for the next few years. When the Lieksa and Särkivaara substations are refurbished towards the end of the decade, the Lieksa station will gain a second reactor – smaller than the one to be installed in Kontiolahti – to alleviate the occasional voltage difficulties. The 110 kV substation at Savonlinna will be renewed in 2025. In the long term, Fingrid has prepared the Huutokoski–Kontiolahti and Kontiolahti–Alapitkä 400 kV transmission line connections in land use planning.

An investment decision has been made to build connection substations to Hovinpaikka and Happola in the region. The connection substations will be added to the most fault-prone transmission lines, in order to improve system security and facilitate outages; the purpose is not to boost the connection capacity. In practice, such substations would be simplified and structurally lighter than the traditional ones, and they would cost less than a traditional main grid substation.

The Lake Line 2 connection to Cross-section Central Finland from the Nuojuankangas substation to Huutokoski will be completed in 2026, passing through the region.



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Pori and Rauma planning area

Description of the area

The Pori and Rauma region is significant on a national level in terms of electricity generation, as it has more than 3,000 MW of electricity generation capacity. The largest power plant is the Olkiluoto nuclear power plant in Eurajoki, and electricity is also generated at industrial and district heating CHP plants, condensing power plants, hydro power plants, and wind power plants, among others. In addition, two HVDC transmission links to Sweden run from the Rauma substation located in the area. Energy-intensive industry forms a large share of the load in the area. The area contains, for example, forest, metal and chemical industry. The planning area's population is approximately 300,000. Due to its high electricity production and cross-border connections, there is a large power surplus in the area. In order to transmit the surplus away from the area, the area's 400 kV main power transmission grid is well meshed and has a good transmission capacity. The Pori and Rauma region is connected to the 400 kV main electricity transmission grid via the transformer substations at Rauma and Ulvila. Electricity is transmitted to consumers within the area by means of 110 kV ring and radial networks from the transformer substations.

Recent investments in the Pori and Rauma grid

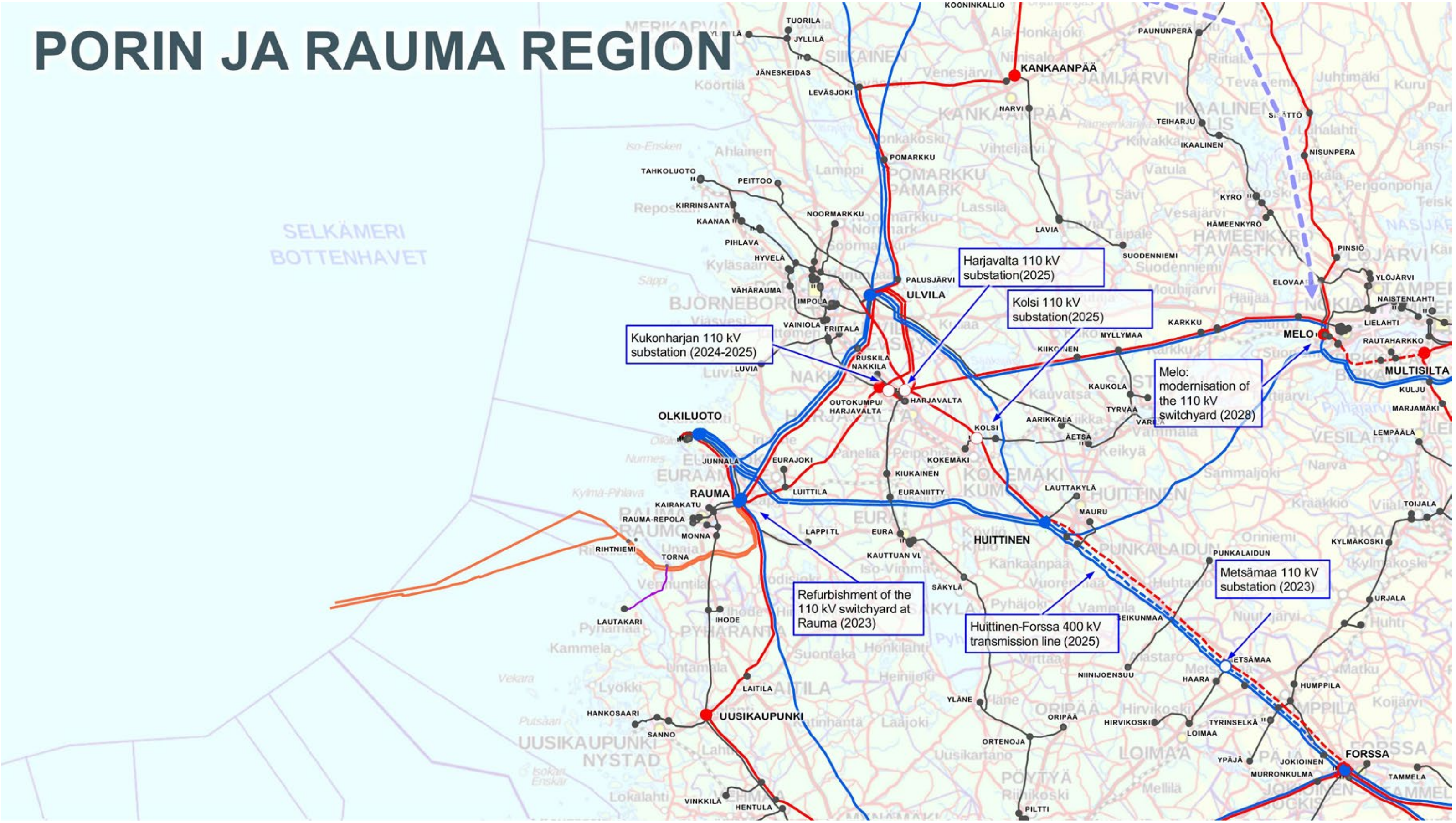
Many investments have been made in the main grid in the Pori and Rauma region in recent years. The new 400 kV Ulvila–Kristinestad transmission line, constructed in place of the ageing 220 kV transmission line, was completed in 2014. In conjunction with this, the 400 kV and 110 kV switchgear at the Ulvila substation was also renewed, and the 220 kV switchgear was phased out. The new 400 kV transmission line is part of the 400 kV west coast ring network (Coastal Line) extending from Pori to Oulu, which was completed in 2016.

The area's 400 and 110 kV main grid was markedly reinforced at the turn of the decade to connect the Olkiluoto 3 nuclear power plant to the main grid and due to increased cross-border connection capacity. In addition, the area's 400/110 kV transformer capacity was increased by renewing one Ulvila transformer and by adding a third transformer in Rauma. The cross-border capacity between Sweden and Finland was reinforced by 800 MW at the start of the decade, when the Fenno-Skan 2 HVDC connection from Rauma to Finnböle was completed in 2011. The modernisation of the Olkiluoto A substation and the new 110 kV Uusikaupunki substation were completed in 2019.

Development plan for the Pori and Rauma region area

Ageing substations and transmission lines will be renovated and renewed in the future: The 110 kV Rauma switchgear will be modernised in 2023. A new 400 kV connection from Huittinen to Forssa will be built in 2025. The ageing 110 kV Kolsi–Forssa transmission line will be modernised between Huittinen and Forssa on the lower branch. The new 400 kV transmission line connection between Huittinen and Forssa will improve energy efficiency and system security significantly. The new transmission line connection will enable better maintenance and fault outages without degrading the security of the power system.

According to the Electricity Market Act, the transmission system operator must own the installations required to transmit electricity in the main grid. Main grid electricity passes through three customer-owned substations in the Pori and Rauma region area. As a basic rule, changes in ownership are carried out in conjunction with substation renewal. The construction of the Harjavalta, Kolsi, and Huopila substations is scheduled for the upcoming 10-year planning period.



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Häme planning area

Description of the area

The Häme planning area covers a rather extensive area of three regions: Pirkanmaa, Häme, and Päijät-Häme, which have a total population of approximately 650,000. Electricity consumption in the Häme planning area is mainly due to a few large forestry and metal-industry plants, as well as consumption by the public sector, services, SME industry, and households. Consumption by civilians in the Häme area is increasing most rapidly around Tampere, Hämeenlinna and Lahti. Elsewhere in the area there is an increase in electricity consumption, though this is smaller than in the town and city areas. The cities and towns in the Häme area contain power plants that generate both electricity and district heating. In recent years, the amount of electrical energy generated has decreased. In addition, there are some electricity and heat plants operating in connection with industrial plants in the area, as well as a few waste-to-energy plants. There are hydro power plants in Tampere, Nokia, and Hämeenkyrö. Fingrid's 320-megawatt reserve power plant is located in Forssa. The power plant is used as a fast disturbance reserve.

In the Häme planning area, the 110 kV grid is connected to the 400 kV main power transmission grid via transformer substations in Kangasala, Lavianvuori, Forssa and Hikiä. Electricity is transmitted to consumers within the area via 110 kV meshed grids between transformer substations.

Recent investments in the Häme grid

Previously, the electricity deficit in the Häme area was mainly fed via the two transformers at the Kangasala transformer substation. As electricity consumption increased, the transformer capacity of Kangasala's two transformers was no longer adequate, and a new transformer substation was completed in Lavianvuori in 2015 along the 400 kV Hikiä–Kangasala transmission line on the border between Kangasala and Valkeakoski. In addition to the Tampere region, consumption is centred in Valkeakoski and a new substation is located closer to consumption in order to reduce the cost of losses. In connection with the project, the 110 kV Tikinmaa substation was phased out, and the 110 kV transmission lines were extended to the 110 kV switchgear at Lavianvuori.

Electricity transmission needs were growing in the west-east direction, firstly due to new wind power and nuclear power plants that are under construction or being planned, and secondly as electricity production capacity is phased out. Development of cross-border connections also increases the need for electricity transmission in Southern Finland's 400 kV grid. A new 400 + 110 kV transmission line was constructed between Forssa and Hikiä. The transmission line replaces the old 110 kV transmission line, which is a part of the Rautarouva connection built between Imatra and Turku in the 1920s. The old line was in poor condition. An extension of the 400 kV substation in Forssa was completed at the same time, to cater for the new transmission line.

A capacitor was added to the Melo substation in 2016 to support the area's voltages during faults and maintenance outages. The old 110 kV Vanaja–Tikinmaa transmission line, which was in poor condition, was replaced in 2018, increasing the transmission capacity of the line. In addition, the load capacity of the 110 kV transmission line from Melo to Seinäjoki was increased in 2018 by replacing individual towers, to improve system security in the area.

In 2019, the last section of the Rautarouva line between Hikiä and Orimattila was completed when the line was renewed with a 400 + 110 kV structure, and a new 110 kV substation was constructed in Orimattila. The entire Rautarouva connection from Turku to Imatra has now been replaced by a new transmission line.

Development plan for the Häme region

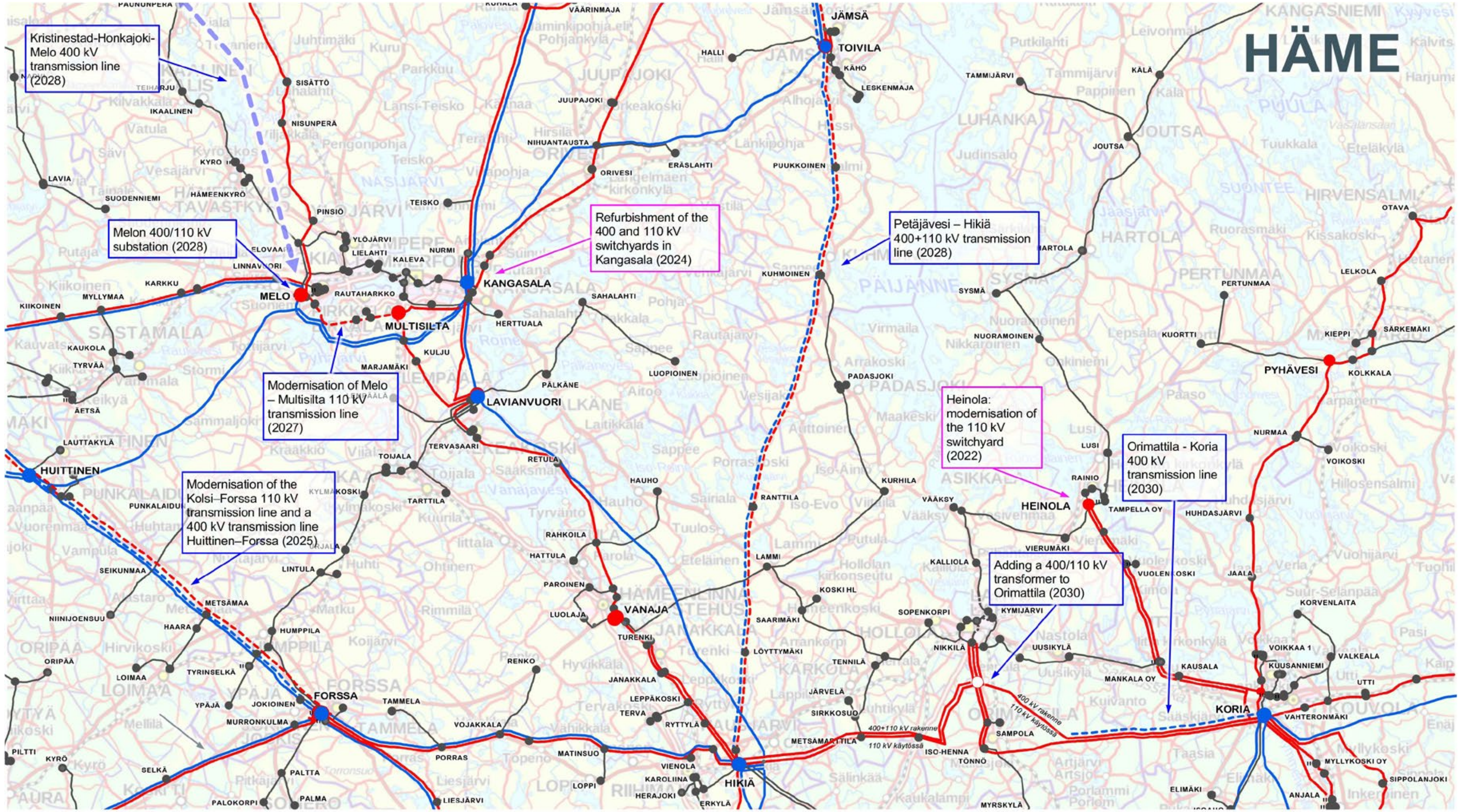
The Kangasala substation will be refurbished in 2024 to maintain the condition of the substation.

There are a few old transmission lines on wooden tower structures in the Häme review area, and these will

be renewed. One particular focus is the modernisation of the Melo–Multisilta transmission line, planned for 2027.

A 400 kV transmission line is planned for Melo in 2028. The wind power from Western Finland must be transmitted along a 400 kV network to Southern Finland, and the best means of implementing this is currently under consideration. When the transmission line is constructed, a 400/110 kV transformer substation will be built in Melo, and the old 110 kV switchgear will be modernised. There are lots of wind power plans for the Parkano area, and the sites will be difficult to connect to the main grid with the current infrastructure. One solution would be a 400/110 kV transformer substation, and the potential location of this will be confirmed during the route design for the Åback–Melo transmission line. The transmission lines to Cross-section Central Finland must be extended from the latitude of Jyväskylä towards consumption centres in the south. In 2028, the Forest Line will be extended from Toivila to Hikiä. The connection is planned with two transmission lines, and it will be constructed in place of the old 220 kV structural transmission lines. A 110 kV transmission line will be added on the lower branch of the transmission line connection.

Towards the end of the planning period, a transformer will be built at the Orimattila substation, and a 400 kV transmission line will be built between Orimattila and Koria. The line is part of the Hikiä–Koria 400 kV connection, which is being constructed to increase transmission capacity in the east-west direction.



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Southwest Finland planning area

Description of the area

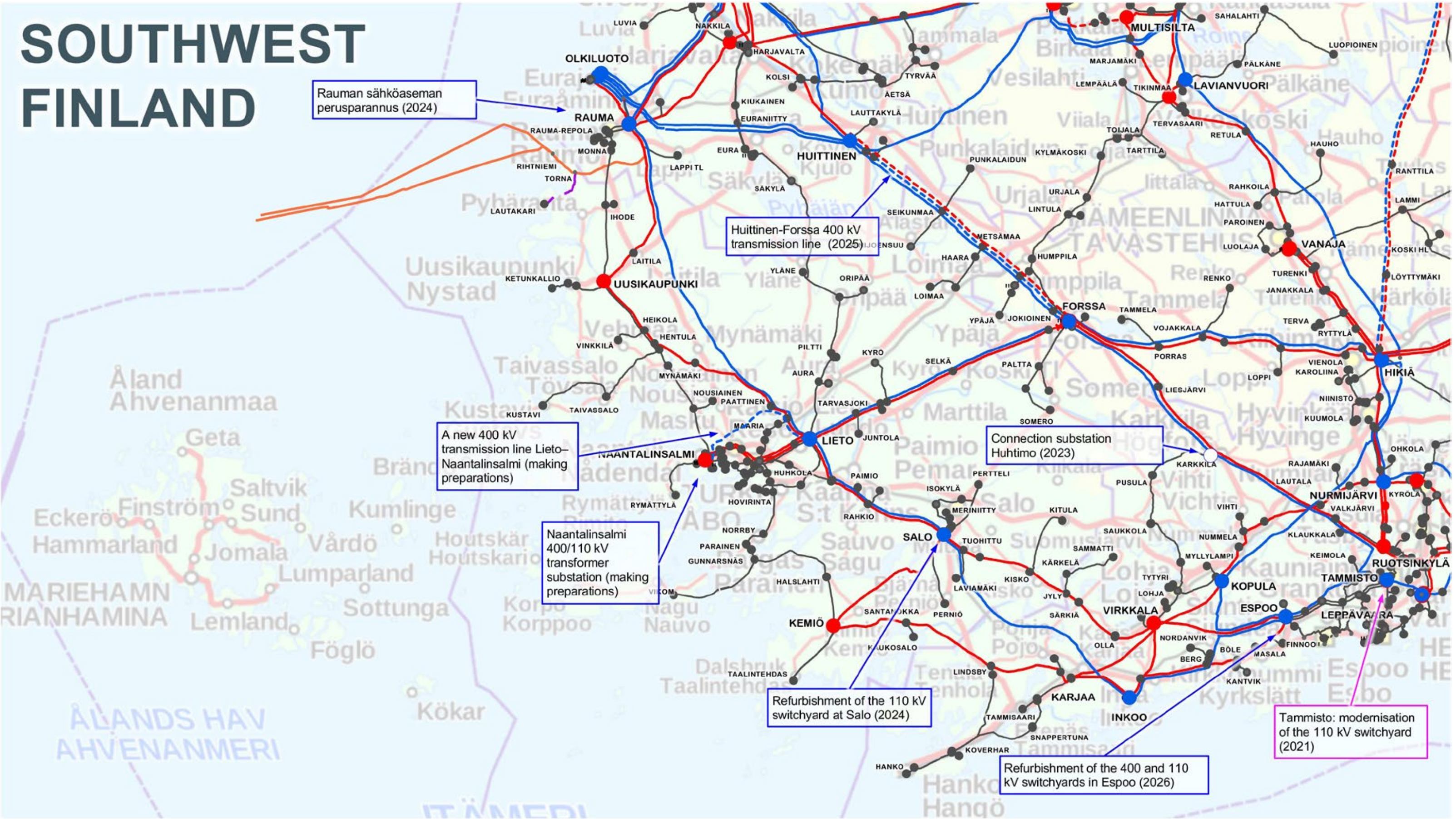
Electricity consumption in the Southwest Finland area primarily comprises consumption by the public sector, services, SME industry, and households. The planning area has a population of approximately 430,000. The majority of the electricity generation in Southwest Finland is located in Naantali, where district heating and steam for industrial needs are generated in addition to electricity. In Southwest Finland, the 110 kV electricity grid is connected to the 400 kV main power transmission grid via 400/110 kV transformer substations in Lieto, Forssa, and Salo. Electricity is transmitted to consumers within the area by means of 110 kV meshed grids from the transformer substations. An HVDC transmission link runs from the Naantalinsalmi substation to the Åland Islands. The transmission capacity of the HVDC connection constructed by the Åland Islands' transmission system operator, Kraftnät Åland, is 100 megawatts. The connection currently operates only as a reserve connection to secure the electricity system in the Åland Islands. Discussion is underway concerning the possible use of the cable as part of the electricity markets. Forssa substation has a gas turbine plant with an output of 320 MW. The power plant operates as a rapid containment reserve in the event of disruptions in the power system.

Recent investments in the Southwest Finland grid

The 110 kV main grid substation, which is central to the Naantali region, was replaced by the new Naantalinsalmi substation in 2015. The limited 400 kV switchgear in Forssa was extended to connect the new 400 kV Forssa–Hikiä and Forssa–Lieto transmission lines. The Rautarouva transmission line built in the 1920s between Forssa and Lieto was renewed with a 400 + 110 kV double-circuit tower transmission line in 2018. At the same time, the Forssa substation was expanded and refurbished. The new transmission line serves regional electricity transmission needs in Southwest Finland and significantly improves the main grid's system security in the area.

Development plan for the Southwest Finland area

The existing 110 kV transmission line will be sufficient to meet the transmission needs between Naantali and Lieto during the planning period. Some preliminary consumption and generation projects are taking shape in the area, so the grid will need to be reinforced. If necessary, the grid's transmission capacity can be reinforced by building a 400 kV transmission line connection from Lieto to Naantali. The transmission line could begin operating at 110 kV and switch to 400 kV at a later time. In addition, the 110 kV Salo substation is due for refurbishment in 2024.



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Southeast Finland planning area

Description of the area

The main grid in Southeast Finland has developed around energy-intensive industry, nuclear power, and hydro power. Southeast Finland features a lot of forest industry and some metal, mining, and chemical industry production facilities. The structural change in the industry in recent years has brought great uncertainty with regard to the development of loads. Hydro power is dispersed around the planning area in small units, with the exception of Finland's largest hydropower plant in Imatra, which outputs nearly 200 MW. Hydro power on the Russian side of the border is connected to Imatra by a 110 kV transmission line. There is a connection from the Loviisa nuclear power plant to the Koria transformer substation, which is located in the planning area. In addition, there are also plants which produce electricity and district heating in the area, along with combined electricity and heat production linked to industry. The Southeast Finland area is connected to the 400 kV main power transmission grid via the Koria, Kymi and Yllikkälä 400/110 kV transformer substations. In Kymenlaakso, electricity is transmitted from the Koria and Kymi transformer substations to the surrounding 110 kV ring network. Southern Karelia is fed by the 110 kV ring network that runs east from the Yllikkälä transformer substation. There are three 400 kV transmission connections from Southeast Finland to Russia: two transmission lines from the Yllikkälä transformer substation and one from the Kymi transformer substation.

Recent investments in the Southeast Finland grid

The grid in Southeast Finland saw heavy investment in the 2000s, when electricity consumption increased sharply, particularly in industry. In this period, the existing transmission lines were strengthened and new ones were built, and substations in the area were constructed, modernised, refurbished, and increased in capacity.

The refurbishment of the 110 kV switchgear in Yllikkälä was completed in 2016. The old Rautarouva transmission line, built in the 1920s, has been modernised in its entirety, and the last section in the area – from Koria to Yllikkälä – was completed in 2018. A major substation project was completed in Koria in 2019, and, at the same time, a 110 kV substation was refurbished, the 400 kV switchgear was modernised, and a reactor investment was made.

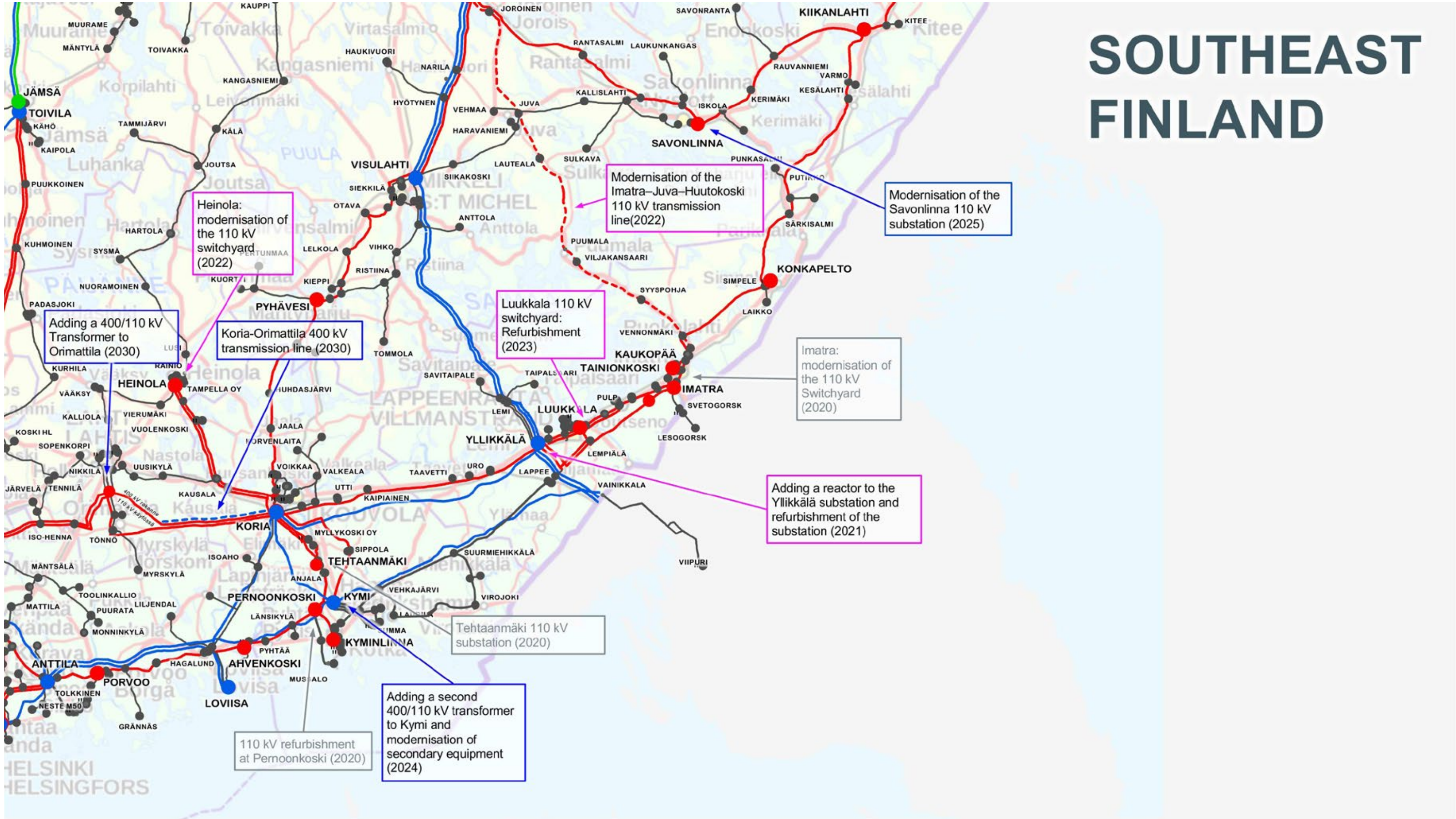
The 110 kV switchgear in Vuoksi was commissioned in 2018, and the section of 110 kV transmission line from Imatra to Lempiälä was modernised to boost transmission capacity in 2019. These investments altered the network topology of the area. The investments were made to increase the transmission capacity in order to transmit electricity to or from the area and address deficits and surpluses. In the long term, the Vuoksi substation needs a 400/110 kV transformer, and preparations have been made for this by building the Yllikkälä–Vuoksi transmission line connection with a 400 kV structure.

New 110 kV switchgear was built in Orimattila in 2019 in connection with the 400 + 110 kV Hikiä–Orimattila transmission line project. This replaced the ageing Nikkilä switchgear, which had acted as a hub for the main grid. The new 110 kV Tehtaanmäki substation was built in Anjalankoski in 2020 to replace ageing circuit breakers. In addition, the 110 kV Pernoonkoski substation was refurbished in 2020, and the 110 kV Imatra substation was modernised.

Development plan for the Southeast Finland area

Thanks to earlier investments, Southeast Finland has sufficient grid capacity and system security. Future projects primarily address the modernisation of the ageing grid. In addition, some major consumption projects are planned for the area, and these may require investments in the main grid.

A reactor will be added to the Yllikkälä substation in 2021. The 110 kV Luukkala and Heinola switchgear will be refurbished in 2023. The 110 kV Imatra–Huutokoski transmission line, which was built in the 1930s, will be modernised in 2022. In the long term, preparations need to be made for a 400 kV connection between Orimattila and Koria at the end of the decade, as west-east transmission requirements increase. In addition, the Kymi substation will be reinforced with the addition of a second transformer in 2024.



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Uusimaa planning area

Description of the area

The Uusimaa planning area encompasses the region between Hanko, Hyvinkää, and Porvoo. The area has a population of approximately 1.6 million. Consumption in the area is concentrated around the capital region. Some of the significant individual industrial electricity consumption sites by size are the Porvoo oil refinery and the paper mill in Lohja. There are many electricity and combined heat and power plants in the area's large cities Espoo, Vantaa and Helsinki. The newest of these is Vantaan Energia's waste-to-energy plant. The Espoo and Western Uusimaa area is fed by the Inkoo, Espoo and Kopula 400/110 kV transformer substations. There are also 110 kV ring connections in the area to the Salo and Nurmijärvi transformer substations. The Espoo substation also has the Estlink 1 connection, a 350-megawatt HVDC transmission link to Estonia. The Vantaa and Helsinki area is fed by the Tammisto and Länsisalmi 400/110 kV transformer substations. North Uusimaa is supplied primarily by the 400/110 kV transformer substations in Nurmijärvi and Hikiä. The main hub in East Uusimaa is the Anttila 400/110 kV transformer substation, which is connected to the 650 MW EstLink 2 HVDC transmission link to Estonia. There are strong 110 kV main grid ring connections between the Uusimaa transformer substations.

Recent investments in the Uusimaa main grid

A second 400/110 kV transformer was added to the Espoo substation in 2017. In the same year, the supply of electricity in Helsinki and Vantaa was secured through the construction of new 400 kV switchgear and a new 400/110 kV transformer. In the past, the 110 kV Espoo–Leppävaara–Tammisto transmission line connection was used as a reserve connection during outages that affected the transformers at Espoo and Tammisto. After the Espoo and Länsisalmi transformer substations were completed, the Espoo-Leppävaara-Tammisto transmission line connections were taken into distribution network use. Likewise, the 110 kV transmission line between Anttila and Länsisalmi also operated mostly as a main grid reserve connection, but after the Länsisalmi project was completed, the transmission line was integrated into the Uusimaa distribution network.

The Inkoo, Nurmijärvi, Porvoo, and Ruotsinkylä substation projects will involve renewing ageing substations or replacing equipment as needed. The Porvoo project was completed in 2018, and the Inkoo and Nurmijärvi projects were completed in 2019. The Ruotsinkylä substation was the last to be completed, with the project concluding in early 2021.

Development plan for the Uusimaa area

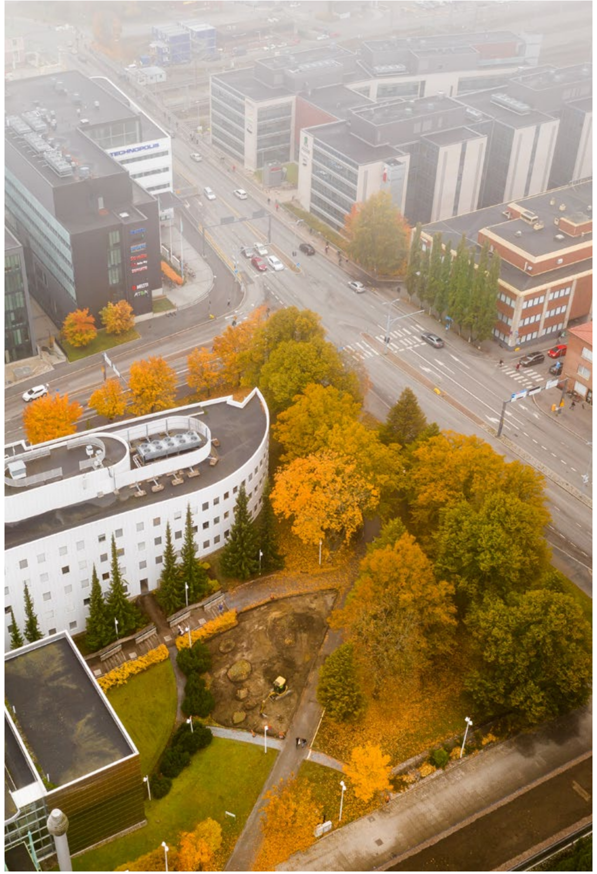
At the moment, work is underway in the area including the partial modernisation and refurbishment of the Tammisto substation, which is due for completion in 2022. The modernisation of the Virkkala substation is just starting, and it will be carried out using new SF6-free GIS technology. The substation will be completed in 2023. The Espoo substation is very important in terms of electricity transmission in the capital region. The substation will be refurbished to maintain a good standard of system security. The project will be completed in 2024. As consumption grows in the western parts of the capital region and generation decreases, new transformer capacity will be required in the area. Fingrid has planned to build the new 400/110 kV Hepokorpi transformer substation along the 400 kV Espoo–Tammisto transmission line. In addition, there are several consumption and generation projects in the area, and the existing substations may need to be expanded to enable these projects to connect to the grid.

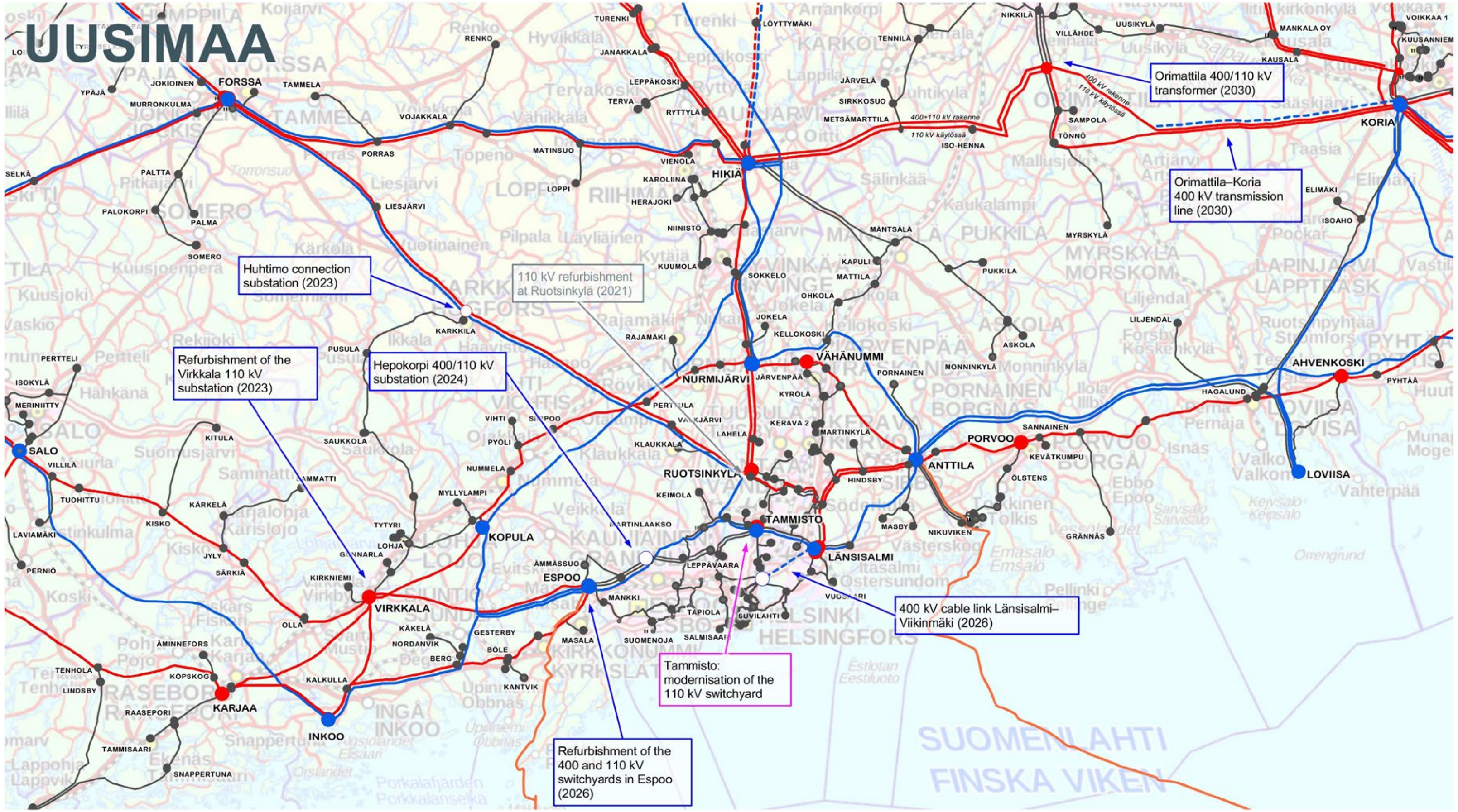
Electricity generation and consumption in Helsinki and Vantaa vary dramatically depending on the time of year. During cold periods, a lot of district heating and CHP plants are used in the area. At this time, the grid has more electricity than production and the electricity surplus is transferred to other parts of Finland via Fingrid's 400/110 kV transformers and transmission grid. The grid has very little electricity production during the summer, during which time large amounts of electricity are fed to the area via main grid transformations. In terms of the grid, the largest transmissions occur in the summer. In the capital region, electricity consumption is increasing while electricity generation is declining. For this reason, the main grid will need to transmit more electricity, especially during the winter. The increase in electricity consumption is partly due to the electrification of heating and transport, population growth in the capital area, and increasing use of cooling in the summer.

When the Länsisalmi substation project was completed, Fingrid started to feed the area with a total of four 400/110 kV transformers. The capacity will be adequate well into the future. Fingrid is planning to develop the capital region grid in cooperation with power generation companies and network operators in the area. As consumption increases and generation decreases, the transmission capacity of Helsinki's 110 kV high-voltage distribution network may be insufficient. The construction of new overhead wires in Helsinki is problematic. To ensure the supply of electricity for functions important to society and residents in the region, Fingrid is preparing a 400 kV cable link from the Länsisalmi substation to the Vanhakaupunki substation in Viikki. According to the Electricity Market Act, such a cable link must be part of the main grid. According to the plan, the cable will be located in an excavated pit and protected. Planning will also take into account the possibility of installing a second cable link later. As the transmission rate increases, the eventual duplication of the cable link can ensure an uninterrupted supply of electricity during faults and maintenance outages. The Vanhakaupunki substation in Viikki has been selected as the terminal station for the cable link because of its central location in terms of the electricity grid.

Forecasting electricity consumption in the capital region is challenging. The area has many potential demand facilities that, if realised, will significantly increase electricity consumption. In addition to consumption, electricity transmission needs are affected by the development of electricity production in the area. Solar power and electricity storage will also change grid transmission needs in the long term. According to the current consumption projections, the 400 kV cable will be needed only after the ten-year review period is over. Due to the City of Helsinki's land-use plans, the plans allow for expedited implementation. The cable is currently scheduled for construction in 2026, and this will enable Helsinki's western boulevard city to be built around the Vihdintie road, when the 110 kV transmission lines along Vihdintie are replaced by cables.

Electricity is often taken for granted and people fail to sufficiently consider the technical limitations, high cost and needs for outages during construction that are associated with moving electricity grid infrastructure or cabling transmission lines. When planning the city boulevards and other construction, it is important to understand that Helsinki will also require electricity in the future.





The pink colour means that an investment decision has been made for the project

The blue colour means that the project is in the planning stage

The grey colour means that the project is complete

* Implementation depends on a customer project.

Summary of investments in the main grid

In recent years, Fingrid's investments have focused on the domestic network, and a record number of investments have been underway throughout Finland. From 2022 to 2031, Fingrid will invest even more – approximately EUR 2.1 billion – in the main grid, which is an average of over EUR 200 million per year. Fingrid's annual depreciation amounts to approximately EUR 100 million. Figure 7 presents Fingrid's investment levels in 2001–2031.

Over the next 10 years, Fingrid's main grid investments will involve developing cross-border connections and Finland's internal main power transmission grid, grid connections for new production, and the renewal and refurbishment of the existing grid. The main grid does not have a maintenance backlog and the grid has been

Investments by network and by year

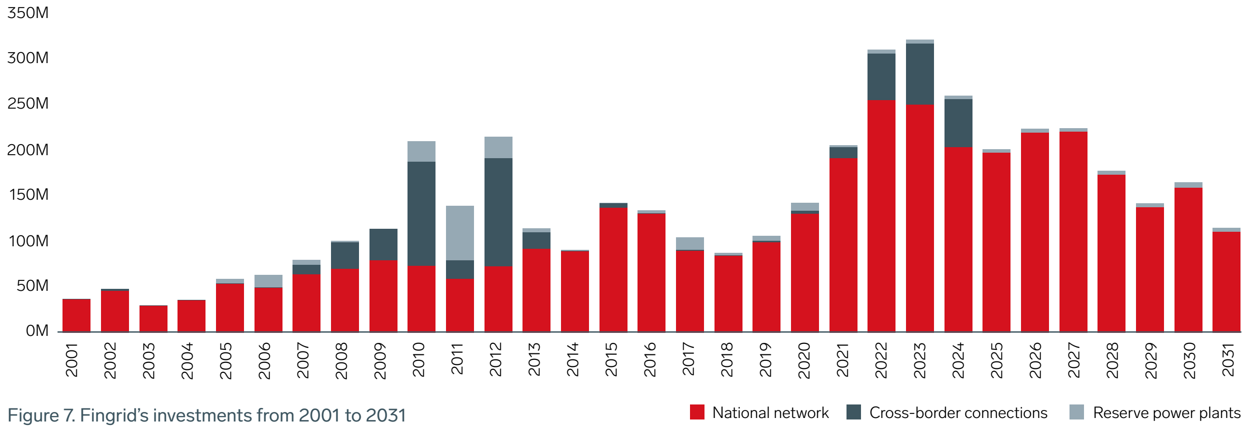


Figure 7. Fingrid's investments from 2001 to 2031

renewed according to the plan and as needed. Fingrid does not have any plans to construct new reserve power capacity during the review period. Figure 8 illustrates how Fingrid's grid investment costs over the next 10 years will be distributed between substation, transmission line, and reserve power projects.

Seventy-five per cent of Fingrid's investment costs are new investments. The change from the previous plan is the result of the north-south connections and new transformer substations that were added to the investment plan. However, when all of the projects are examined individually, the unsatisfactory condition of the existing infrastructure is one of the grounds for investment in two-thirds of projects. In addition to new investments, a large number of substation refurbishments will take place, and ageing 110 kV transmission lines will be renewed during the planning period. Figure 8 presents the number of Fingrid substation projects from 2021 to 2031. It is likely that further substation extensions and new 400/110 kV transformer substations will be implemented due to customer needs that will only become apparent in the future.

During the planning period, refurbishments will be carried out on 400 kV and 110 kV switchgear built in the 1980s, among other things. This switchgear can continue to be used as long as the equipment that has reached

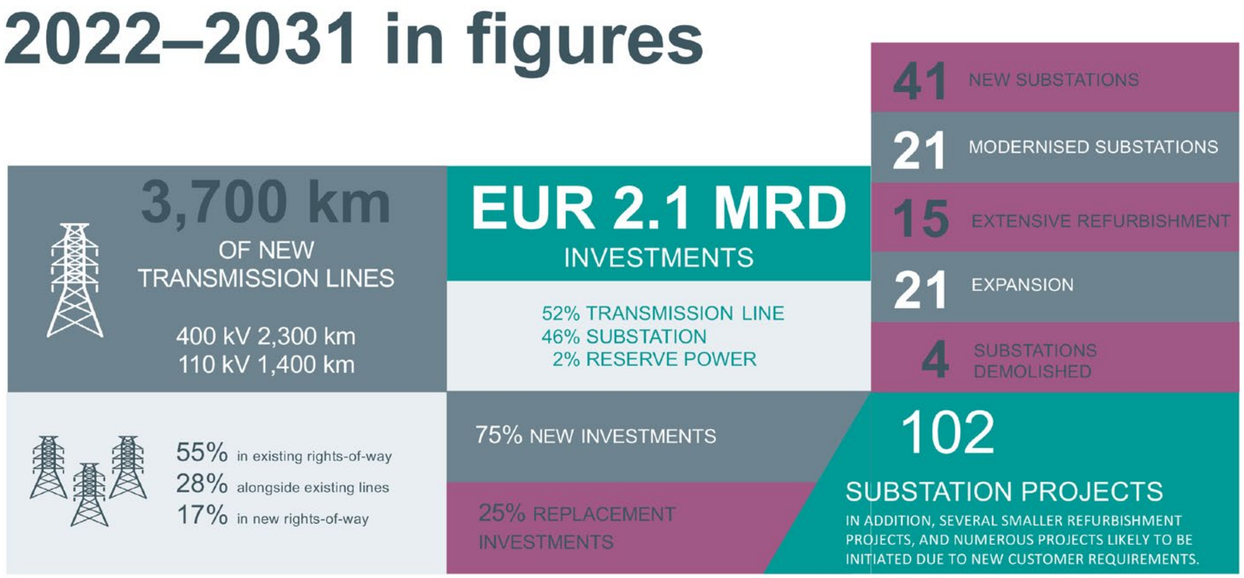


Figure 8. Fingrid's investment plan in figures

the end of its service life is replaced. All transmission lines built in the 1930-1940s will be decommissioned and the majority replaced with new ones during the planning period. Condition assessments will be performed on ageing transmission lines in order to maximise their service life without compromising system security.

In accordance with the nationwide land use objectives stipulated in the Land Use and Building Act, the objective is to primarily utilise existing transmission line routes in the planning of transmission lines. Figure 9 shows that nearly all new main grid transmission lines (approximately 80 per cent) will be constructed in or alongside existing transmission line corridors, so the areas will widen less than when building a completely new right-of-way. The table below shows the development of Fingrid's main grid over the planning period.

Number of transformers and their power	At the beginning of 2021	At the beginning of 2031	New	To be dismantled
400/220, number	5	4	0	-1
400/220, power	2000 MVA	1600 MVA	0 MVA	-400 MVA
400/110, number	55	77	24	-2
400/110, power	22000 MVA	35200 MVA	14000 MVA	-800 MVA
220/110, number	15	10	3	-8
220/110, power	2300 MVA	1400 MVA	550 MVA	-1450 MVA
Transformers in total	75	91	27	-11
Total power of transformers	26300 MVA	38200 MVA	14550 MVA	-2650 MVA

Number of substations	At the beginning of 2021	At the beginning of 2032	New	Dismantled/decommissioned
Number of substations	118	158	44	-4

Length of transmission lines	At the end of 2020	At the end of 2031	New	Dismantled/decommissioned
440 kV	5,200	7500	2300	0
220 kV	1,300	500	0	-800
110 kV	7,300	7600	1400	-1100
Total	13800	15600	3700	-1900

Figure 9. Development of main grid assets from 2021 to 2031.

The phasing out of the 220 kV voltage level south of Oulujoki can be seen as a decrease in 220/110 kV transformers. In addition, the number of 220 kV transmission lines will decrease. Some of the transmission lines will be decommissioned, and some will be operated at 110 kV as part of distribution networks. More than 2,000 kilometres of new 400 kV transmission lines will be built. These transmission lines will create a strong main power transmission grid, supplemented by 110 kV lines. New transformer substations and new transformers to be constructed at transformer substations will tie different voltage levels to one another more strongly.

The main grid development plan provides a picture of Fingrid's plan to develop its grid. Fingrid updates its plan as a continuous process, in accordance with the changing operating environment. The development plan contains some uncertainty related to new consumption and the connection of new power plants to the grid. In addition, the operating environment also contains major uncertainties associated with the energy revolution and the speed of change in the structure of electricity production, among other things. For example, the amount and geographical positioning of wind power, as well as the speed of electrification of society, have a particularly significant impact on the need and timing of Fingrid's investments. Fingrid is cooperating closely with customers and preparing for possible new connections. Investments in the grid will be carried out as needed and at the right time. For the latest information about the investment plan, please visit Fingrid's website or contact us. Fingrid will publish its next main grid development plan in 2023.

Changes in the operating environment and future outlooks

The energy sector plays a key role in combating climate change. The structure of electricity generation is changing as the use of renewable energy increases and adjustable fossil power decreases. The amount of wind and solar energy will increase rapidly. In the electricity system, the change in production structure will cause intermittent shortages of power and flexibility, and system inertia and short-circuit power, which will create business opportunities for flexible production and consumption and electricity storage technologies.

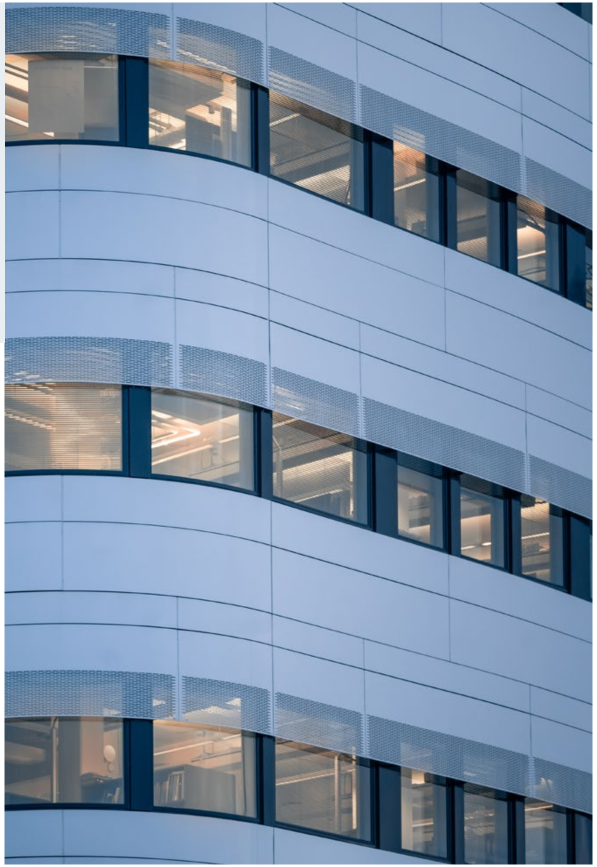
Fingrid strives to actively highlight improvements in electricity market operations and seek new operational solutions, to ensure that the electricity system functions reliably, and to find a market-based balance between production and consumption. Smart grid technology will create new business opportunities for existing and new operators. Digitalisation enables the effective distribution of market information and the development of new tools to manage a changing and increasingly complex electricity system.

At the same time as the electricity production structure is changing, society is becoming more electrified and its dependence on electricity is increasing. Consequently, serious disturbances of electricity supply have become one of the most important security threats to society.

At the same time as the electricity production structure is changing, society is becoming more electrified and its dependence on electricity is increasing.

Implementation of Fingrid's investment programme, market promotion and operational development improve the reliability of the electricity supply and readiness to act in crisis situations. Active participation in the development of European rules and cooperation in the Baltic Sea region is also essential.

The starting points for Fingrid's planning are forecasts and scenarios, which seek to illustrate and make preparations for the development pathways relevant to the planning of the main grid. Fingrid's scenarios for 2035 and 2045, and the grid reinforcements required by them, are described in Fingrid's network vision, which was published in January 2021. The main grid development plan focuses on developments in the 2020s.



Climate change mitigation

Climate change mitigation requires swift action to achieve climate neutrality. Finland has set itself the target of becoming carbon neutral by 2035 and carbon negative soon after. Industrial low-carbon roadmaps, which have assessed the realisation and impacts of this target, indicate that the carbon-neutrality target will significantly increase electricity consumption, as replacing fossil fuels with electricity generated using renewable energy sources is an effective means of reducing emissions from industry, heating, and transport. This can only succeed if the technologies required by the transformation, such as electric cars, heat storage facilities, and new industrial processes, are competitive. Increased demand for clean electricity also lays the foundations for offering electricity on market terms. Indeed, several power purchase agreements (PPAs) have already been concluded between wind power operators and industries that need electricity. In Fingrid's estimation, the emission-reduction targets will result in a structural increase in electricity consumption.

In addition to Finland's own climate targets, broader European targets and developments will have a significant impact on the required investments in Finland's main grid. The European Union has set stricter emissions targets in recent years: the targeted reduction in emissions by 2030 is now 55 per cent, compared with the previous target of 40 per cent, in relation to the emissions in 1990. The EU aims to become climate-neutral by 2050. Discontinuing the use of fossil fuels throughout the EU will be an enormous change, which will give rise to opportunities for companies operating in Finland to generate electricity and fuels derived from electricity or other products for export. Consequently, developments throughout Europe may cause Finland's electricity consumption to increase by much more than the minimum requirement to meet Finland's own targets alone.

Development prospects of electricity consumption

Electrification potential of heating

The increase in electricity consumption for heating is driven primarily by the growth in the number of heat pumps for household heating and for district heating. The most significant fossil fuels are the oil used to heat some buildings, as well as the coal, natural gas, and peat used to generate district heat. Large heat pumps and electric boilers can replace fossil fuels in the generation of district heating, and similarly, property-specific heat pumps can replace oil heating. In 2019, fossil fuels accounted for more than 20 TWh of energy used for heating, so the preconditions are in place for an increase in electricity consumption, although improvements in energy efficiency and global warming will reduce the need for heating overall.

The calculations on which the main grid development plan is based foresee an increase in electricity consumption for heating of approximately 6 TWh from 2019 to 2030. The largest increase will occur in cities where the current fossil fuel combined heat and power plants will be replaced by heat pump solutions, leading to increased electricity consumption and lower generation. In practice, this will require the reinforcement of the electricity supply to growth centres.

The main grid development plan makes preparations for the realisation of ambitious electrification scenarios.

Electrification potential of industry

The action required to enable low-carbon industry and the increase in the need for electricity are covered in depth in the industrial low-carbon roadmaps. The main grid development plan makes preparations for the realisation of ambitious electrification scenarios. Over the long term in particular, the increase in electricity consumption by industry will be the main contributor to the rise in Finland's electricity consumption and the size of its electricity system. Whereas the growth potential for electricity consumption in heating and transport is constrained by the country's population, the amount of industry is most affected by Finland's competitiveness as a place to invest. Thanks particularly to its favourable wind power conditions, Finland is in a good position to generate large volumes of clean, competitive electricity, and Fingrid is making preparations for a significant increase in industrial electricity consumption.

Different industries have different reasons for the rise in electricity consumption. The low-carbon roadmaps prepared for the forestry industry do not foresee a significant increase in electricity consumption. In the metal industry, electricity consumption will rise, especially in steel production. In the chemical industry, the growth in electricity consumption will be based on the replacement of fossil fuels by electricity for producing process heat, and the exploitation of power-to-X processes for producing raw materials, especially hydrogen[3]. In addition to the increase in the volume of electricity consumed by incumbent industries, clean and inexpensive electricity may attract new industrial investments to Finland. The potential business sectors include the production of fuels made using electricity, data centres, and battery manufacturing. The calculations on which the main grid development plan is based foresee an increase in industrial electricity consumption of 10–20 TWh from 2019 to 2030.

[3] https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/162705/VNTEAS_2021_4.pdf s. 39

Electrification potential of transport

The introduction of electric vehicles will reduce oil consumption in road transport and will increase electricity consumption. At the same time, the total energy consumption of transport will be significantly reduced, since electric motors are significantly more efficient than internal combustion engines. If the entire passenger car fleet in use (2018: 2.7 million vehicles) were electrified, the consumption of electricity would increase by 6–8 TWh, depending on the specific consumption of the vehicles. Estimates of the number of electric vehicles in Finland in 2030 range from the official target of 250,000 vehicles to 700,000–800,000 vehicles, in which case the consumption of electricity would increase by 0.5–2 TWh.

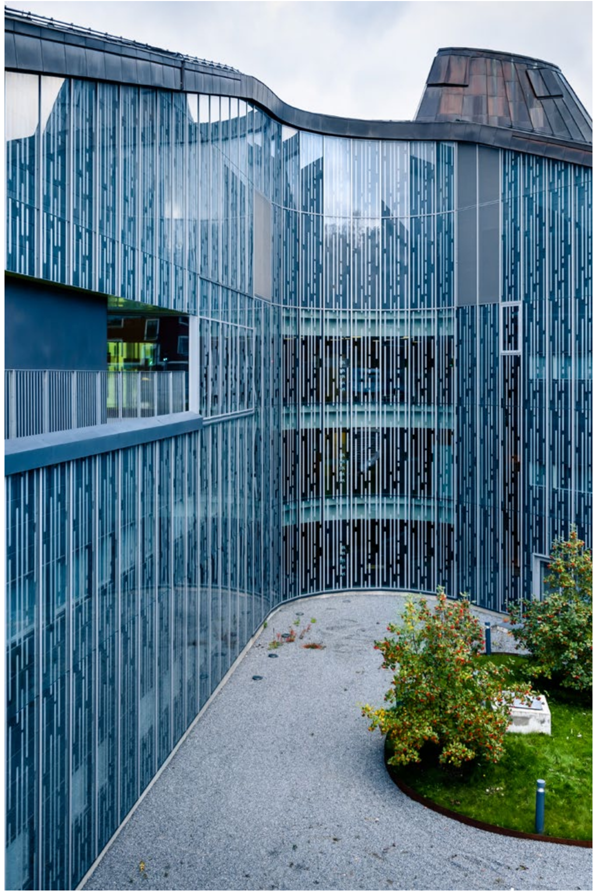
Electrification of heavy vehicles and an increase in rail transport would also increase the consumption of electricity, but their impact on electricity consumption by 2030 is estimated to be limited. One element of uncertainty that should be kept in mind is that if instead of using electricity, transport were powered by hydrogen produced with domestically generated electricity, the total energy consumption would fall markedly less than in the fully electric scenario, which would mean higher overall electricity consumption.

Other electricity consumption

Other electricity consumption is not expected to change significantly. As a result of improvements in energy efficiency, the electricity consumption in households and, especially, the service sector will fall, but the projected population growth will lead to increases in consumption. Moreover, as the volume of transmitted electricity rises, transmission losses will increase somewhat. These factors are expected to offset each other to a greater or lesser extent, so the consumption of electricity beyond heating, transport, and industry will not change substantially.

Summary

Electricity consumption will have significant growth potential in the future, but the full potential will not even come close to being realised by 2030. Fingrid estimates that electricity consumption will increase by 100–115 TWh by 2030, driven primarily by industry. The growth in consumption will be affected by climate targets and Finland's attractiveness as a place to invest for industries utilising clean electricity.



Prospects for future electricity generation

The change taking place in the structure of electricity generation is one of the key development drivers of Fingrid's main grid development. The central trends are an increase in weather-dependent production, large new nuclear power plant units, a decrease in the amount of controllable generation, and the geographic placement of new generation in the main grid.

Wind power

At the end of 2020, Finland's wind power capacity was 2,586 MW, and its annual output was 7.8 TWh[4], corresponding to about one-tenth of Finland's electricity generation. The generation costs of wind power have been falling substantially for a long time, and the competitiveness of wind power has taken a significant leap forward, especially in the last five years. The most significant factor in the decrease in costs has been the increase in the size of wind turbines and, thereby, the increase in their power output, while investment and operating costs have fallen. Up to April 2021, Fingrid had received wind power connection enquiries for a total capacity of 90,000 MW, and the rate at which new enquiries have been submitted in recent years has increased markedly. Unlike many other European countries, Finland still has plenty of space for onshore wind turbines. Although a significant proportion of the enquiries will not lead to actual projects, the size of the project base will not restrict the growth of wind power in the next few years. The growth will be based on the price competitiveness of wind power against other forms of generation, the competitiveness of Finnish wind farms against other Nordic countries, the increase in the consumption of electricity, and the interest of the purchasers of electricity to procure wind power electricity by means of PPAs. The increase in the consumption of electricity will be a particularly powerful driver of growth in wind power and, therefore, the growth forecasts for wind power are tied to the growth forecasts for electricity consumption.

The volume of wind power in Finland is expected to grow by at least 1,000 MW per year in the 2020s, leading to a capacity of 10–15 GW by 2030, with a corresponding energy output of 33–53 TWh. If this comes to fruition, wind power will account for 30–50 per cent of total electricity consumption. Figure 10 illustrates this trend. The estimate for the coming years is based on public investment decisions and the connection agreements that Fingrid has made with wind power operators. Over the

Fingrid is making preparations for a significant increase in wind power

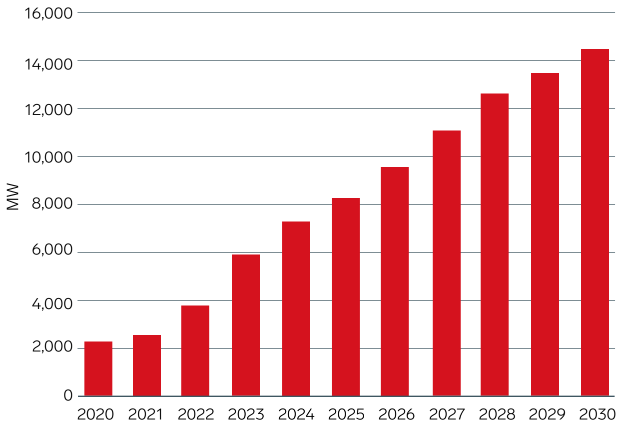


Figure 10. Baseline scenario for the increase in wind power, which is taken into consideration in network planning.

[4] https://tuulivoimayhdistys.fi/media/tuulivoima_vuositilastot_2020_julkaisuun-10.2.pdf

longer term, the growth potential of wind power depends mainly on the increase in electricity consumption.

Forecasts of the growth in wind power have been raised significantly in comparison with previous plans, mainly due to the more stringent climate targets and the increase in electricity consumption estimates. At least in the first half of the 2020s, wind power is expected to be concentrated onshore, but the scenario that envisages offshore wind power becoming more widespread will be relevant, especially in the latter half of the 2020s.

More than 60 per cent of the wind power capacity is expected to be built to the north of Cross-section Central Finland, which is a key part of the main grid with regard to transmission capacity. This will increase the need for north-south transmission capacity in the main grid. If wind power grows more rapidly than expected, it will increase the need to connect the wind power to the grid and transmit the power from north to south. A more even distribution of wind power locations across Finland, including in Southern Finland and the southern parts of Eastern Finland below Cross-section Central Finland, would reduce the need for these investments.

[5] https://energiavirasto.fi/-/aurinkosahkon-tuotantokapasiteetti-jatkoi-kasvuaan-vuonna-2019-vuosikasvua-64-prosenttia

Solar power

The generating capacity of solar power has increased sharply in recent years in Finland. At the end of 2019, the capacity stood at 198 MW, according to the Energy Authority[5]. Fingrid estimates that the capacity of solar power will continue to grow strongly: In Fingrid's scenarios, Finland's solar power generation capacity will vary from approximately 1.5 GW to 3 GW in 2030. Although the annual output corresponding to these generation capacities is only 1–3 per cent of Finland's electricity production, the effect will be significant, particularly in the summer during times of low electricity consumption. The development of solar power has begun to manifest itself in the form of connection enquiries submitted to Fingrid. The largest of the planned projects are hundreds of megawatts.

Nuclear power

Finland's nuclear power output has typically been 22–23 TWh per year, which accounts for about one-third of total generation. According to planned construction and commissioning schedules, construction of the Olkiluoto 3 and Hanhikivi 1 nuclear power plants will double

Finland's current nuclear power capacity during the review period. Similarly, the current lifespan of the Loviisa 1 and 2 units will expire during the investigation period and, if the units are then decommissioned, nuclear power in Finland would amount to around 35 TWh/a in the 2020s and 2030s. The corresponding production volume would also be realised if the Hanhikivi 1 were further delayed, but the operational lifetime of the Loviisa units would be correspondingly extended. In this case, however, the north-south transmission requirement would be lower. Modular small-scale nuclear power plants are not expected to be commissioned in the 2020s.

Other forms of production

No significant changes in hydro power generation are expected during the review period. Hydro power is an important stabiliser in the electricity system due to its renewability, adjustability, and significant capacity for energy storage.

The volume of electricity generated at combined heat and power (CHP) plants has been in the range of 21–22 TWh in recent years, with the exception of 2020, which was characterised by the coronavirus crisis and strikes in the forestry industry, leading to total generation of less than 18 TWh. The abandonment of fossil fuels is highly likely to reduce the CHP capacity and the total output in the future. The CHP plants being renewed may also be of a smaller size than existing plants, especially with regard to plants with additional condensing capacity, referring to the electricity generation capacity exceeding the heat requirement that is comparable to condensing power. When CHP plants have been modernised in recent years, some have been replaced by solutions that only generate heat, thereby foregoing the potential for generating electricity entirely. For the reasons mentioned above, CHP capacity and the generation of heating-related CHP electricity are expected to decrease from the current level during the review period. By contrast, industrial CHP electricity generation is expected to grow as a result of the increase in biofactory projects, but this will take place over a longer period of time. The refining of waste liquors and residues into products more valuable than electricity and heat might also result in a decrease in industrial CHP production.

The market situation for power plants that only produce condensing electricity has been very difficult for some time, and a noticeable amount of capacity has been closed or decommissioned. Construction of new condensing capacity is not expected during the review period, and existing condensing power plants are expected to face the threat of closure.

Summary

The total electricity output in Finland will increase significantly, which will enable the growing demand for Finnish electricity to be satisfied and the current import-dominated cross-border trade to be balanced out. The volume of wind power will increase particularly rapidly, and it could become the largest form of electricity generation in Finland sometime this decade. Finland appears to be an attractive place to build wind turbines, especially for onshore wind power. The volumes of nuclear and solar power will also increase. The volume of hydro power is expected to remain steady. The amount of "other thermal power", comprising the output of combined heat and power plants, is expected to decrease as the use of fossil fuels for electricity generation declines.

The volume of wind power will increase particularly rapidly, and it could become the largest form of electricity generation in Finland sometime this decade.

Prospects for electricity storage and demand-side management

Storage

Generation and consumption in the electricity system must be in balance at all times, which means that as electricity generation becomes less adjustable, electricity consumption must correspondingly become more adjustable. As the amount of variable electricity generation increases, there will be a greater need to store electricity and other energy derived from electricity. Storage facilities make it possible to consume electricity when it is available in large volumes at low prices and reduce consumption when supply is limited and the price is high. Potential new storage technologies include grid energy storage (such as batteries, compressed air storage, and pump plants), storage of heat generated using electricity, and storage of hydrogen, fuels, or other intermediate and finished products related to power-to-X processes. In the case of grid energy storage, the system involves large battery power plants connected directly to the main grid, and decentralised batteries for end-users and elsewhere in distribution networks.

The rapid pace of technological development makes it hard to estimate which technologies will prevail in the future. In principle, electricity storage facilities must compete with all the other sources of flexibility in the market, and the market will select the most competitive technologies for each purpose. Overall, the volume of storage facilities is expected to increase significantly.

Demand-side management

There is significant potential for demand-side management, and an increasing part of that potential is expected to be realised for use in the electricity system. Today, households and the service sector make up two-thirds of peak power demand. Smart load control provides significant opportunities for flexibility at the second, minute, and hour levels. Remotely controlled loads and smart control that monitors their status and the balance of electricity supply and demand enable the optimisation of consumption according to consumers' needs while minimising costs and the need for manual control. The consumer benefits in the form of a smaller electricity bill, and the "aggregator" – the party that coordinates the control – can sell flexibility to the electricity market or network operators (in the form of "virtual power plants"). Industrial electricity consumption may offer partial flexibility, depending on the needs of the primary processes involved and the potential for the interim storage of products.

The electrification of transport also promotes a short-term demand-side response. Electric car batteries represent a potential source of energy storage, and controlling their charging can be an important tool in relation to managing the balance between electricity demand and supply. Where smart charging improves overall electricity system efficiency and increases the supply of flexibility, uncontrolled charging has the opposite effect: it increases demand for flexibility and causes power adequacy challenges. This is why it is essential to implement a smart charging infrastructure for electric cars from the outset, and Fingrid's main grid planning is based on the principle that charging will be implemented in a smart manner. The possibility of feeding electricity from vehicle batteries to the electricity grid (Vehicle-to-Grid or V2G) whenever necessary may develop into an important opportunity for balancing the electricity system.

Forecasts

Figure 11 shows Fingrid's forecasts for the evolution of electricity generation and consumption in Finland by 2030. With a significant increase in wind and nuclear power generation, Finland's current dependence on electricity imports is expected to end by the mid-2020s and remain balanced until the end of the 2020s, despite strong growth in electricity consumption.

When planning the main power transmission grid, Fingrid uses a variety of forecasts and scenarios as it strives to prepare for different development paths. The forecasts presented in the plan reflect the best estimate at the time of writing and will be updated whenever necessary. In addition, various sensitivity analyses or alternative scenarios will be prepared for different purposes, with changes to variables such as the volumes and locations of generation and consumption.

In comparison with previous plans, the more stringent climate targets and the continuous decline in the costs of technology have significantly increased the pace of change. The goal of forecasts and scenarios is to find triggers and value ranges to support grid development and enable timely and appropriate investments. The forecasts and scenarios on the development of production capacity and consumption apply to the entire system and contain assumptions about the geographical location of production and consumption as well as the technologies used and their properties such as wind power technology, consumption profile and the amount of available flexibility resources. Major deviations from these assumptions may increase or decrease the need for investments compared to the ones presented in the development plan, even if the overall trend is in line with the scenario. Regional forecasts are used in regional grid planning.

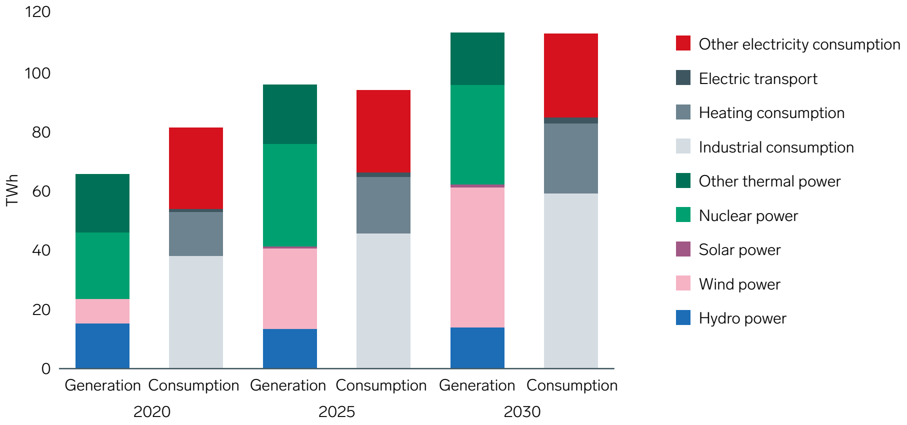


Figure 11. Fingrid's forecasts for the evolution of electricity generation and consumption in Finland by 2030.

Development of the main grid

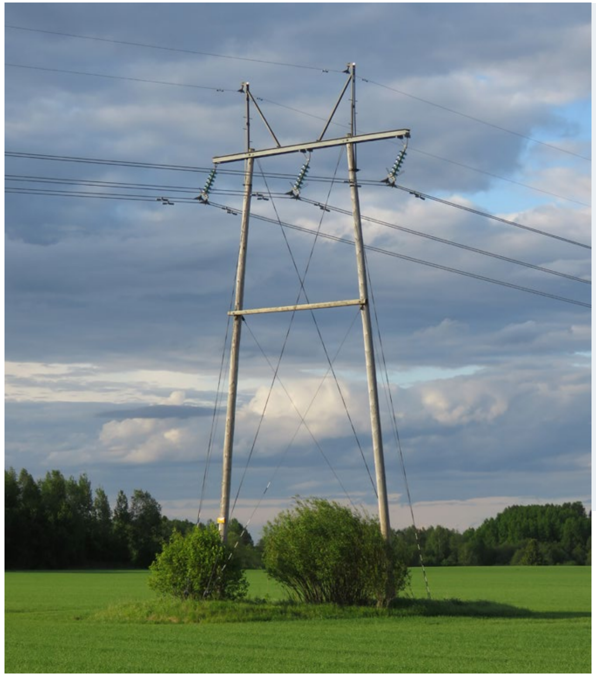
Fingrid's grid development is guided by the obligations of the transmission system operator and the condition and needs of the existing grid. There are also many different boundary conditions that affect the development of the grid. The development of the main grid will provide a reliable, cost-effective platform for a clean electricity system.

The key objectives are to ensure that

- the transmission capacity is sufficient for the needs of the customers, markets and society
- operations are efficient and safe
- a good standard of quality is achieved.

In order to achieve these targets, Fingrid operates interactively with its customers, other main grid companies, the authorities, landowners and other partners, and ensures availability of services in the sector. The company's personnel has an excellent grasp of issues specific to the industry. Fingrid develops its operations with a long-term focus by learning from its own experiences and those of other pioneers, and it manages the main grid in accordance with the principles of good asset management.

Occupational safety, environmental and land use matters are taken into consideration at all stages of main grid life-cycle management. The general safety of stakeholders, company employees, and service providers, as well as environmental safety, are actively promoted by means of new operating methods, training and guidance, and monitoring of operations. Responsible business practices are Fingrid's strategic choice, which also includes ensuring the responsibility of supply chains.



In order to achieve these targets, Fingrid operates interactively with its customers, other main grid companies, the authorities, landowners, and other partners, and ensures the availability of services in the sector.

Principles of grid development

The starting points for grid development are the future needs of customers and society, promoting the operation of electricity markets in the European and Baltic region, maintaining system security, cost-effectiveness, and managing the ageing of the grid. The revolution in the electricity system will lead to significant changes in transmission requirements, making them more difficult to forecast. Fingrid's grid development is based on extensive and interactive cooperation with numerous stakeholders. Fingrid acquires information about its customers' needs and plans by means of confidential and systematic cooperation with the customers. The development needs of electricity markets are analysed in cooperation with the market parties. Supranational forecasts and analyses are also carried out in cooperation with other main grid organisations.

In terms of grid development, Fingrid strives to manage the environmental and safety impacts of its operations. The aim is to minimise the harmful impacts within the limits of public interest and the technical and economical boundary conditions. Main grid construction, use and maintenance cause a variety of environmental impacts. Minimising and managing environmental impacts are an important part of Fingrid's practical operating methods. Observing the obligations and guidelines in the legislation and maintaining real-time plans for emergency situations are the cornerstones of environmental management and managing environmental risks. Fingrid is an active participant in land use planning to ensure that the land use reservations required for grid development and the related impacts on the environment are taken into consideration during the zoning of land areas. In accordance with the nationwide land-use objectives stipulated in the Land Use and Building Act, the primary objective is to utilise existing transmission line routes in the planning of transmission lines.

Grid development is governed by European network codes and guidelines. The application of dimensioning regulations and transmission capacity specifications is governed by Fingrid's internal guidelines. Fingrid has committed to these principles in main grid service contracts. Fingrid can decide to use more reliable dimensioning in order to reduce particularly harmful risks. Fingrid uses the operational performance requirements and connection conditions that it has set to ensure that the power system is dimensioned adequately in terms of disturbance tolerance.

Fingrid's main grid is developed over the long term in a manner that provides technical and economic optimisation while simultaneously ensuring future operating conditions. For this purpose, Fingrid compiles and maintains a main grid development plan that is coordinated with grid plans covering the Baltic Sea region and all of Europe. The grid development plan and investment programme are based on future transmission forecasts and grid plans drawn up on the basis of grid renewal needs. The aim is to align grid reinforcement needs with maintenance, refurbishment and renewal needs. The investments to be implemented are beneficial in terms of the national economy or essential to meet the dimensioning principles. Furthermore, the projects selected for implementation must be cost-effective and in line with the company's finances.

The success of grid development is assessed by analysing the adequacy of capacity, system security, project quality, and costs, and by monitoring the realisation of development projects. The principles of grid development and maintenance management are available on Fingrid's website.

Development process

International main grid development cooperation

International network planning takes place at several levels. These include European, Baltic Sea region, and Nordic plans. In addition, joint bilateral plans are made with the transmission system operators in Finland's neighbouring countries.

European cooperation takes place under the auspices of the European Network of Transmission System Operators for Electricity (ENTSO-E). ENTSO-E comprises 42 transmission system operators from 35 countries. The purpose of the organisation is to develop electricity markets and improve cooperation between transmission system operators, and to harmonise market and technical regulations in cooperation with the Agency for the Cooperation of Energy Regulators (ACER). ENTSO-E is also tasked with preparing ten-year network development plans (TYNDPs) for European electricity networks. The European TYNDP is based on the future scenarios developed jointly by ENTSO-E and ENTSOG, which represents gas network companies.

Network planning is also conducted on a regional level under the auspices of ENTSO-E. Finland is part of the Baltic Sea regional planning group, which also includes Estonia, Latvia, Lithuania, Sweden, Norway, Denmark, Germany, and Poland. At the start of 2021, the transmission system operators in the Baltic Sea region initiated the Baltic Offshore Grid Initiative, which is a new project focusing on the promotion of the infrastructure needed for offshore wind power.

Led by the European Commission, the Priority Corridor Baltic Energy Market Integration Plan (BEMIP) regional group includes the same countries as ENTSO-E's Baltic regional group. In addition to the transmission system operators, the BEMIP group includes the ministries and regulators of the countries. The primary aim of the BEMIP group is to integrate the Baltic countries with European electricity markets.

In addition to ENTSO-E and BEMIP cooperation, international grid planning cooperation takes place in relation to the Nordic context, especially in matters related to the synchronised area. Together with transmission system operators in the neighbouring countries of Sweden, Norway, Estonia, and Russia, Finland is also performing bilateral studies on topics such as the capacity needs and the location and technology for new connections.

When analysing the need for new cross-border connections, investments are based on calculations of their benefits to the national economy. This means that Fingrid will invest in cross-border connections whose anticipated benefits for market parties are higher than the costs of the investment. Benefits to market parties include benefits to the users of electricity (so-called consumer surplus change) and the benefits to the producers of electricity (so-called producer surplus change), in addition to which the calculation takes in to account the change in congestion revenues collected by the TSOs. Benefits to the adequacy of electricity supply, integration of renewable energy, carbon dioxide emissions, as well as the technical operation or flexibility of the electricity system are also assessed. Similarly, the costs that are taken into account are investment costs, operating and maintenance costs, and environmental impacts. Another factor taken into account is the impact on the system's transmission losses, which may be positive or negative, depending on the project. Such cost-benefit analyses are carried out both at the pan-European level by ENTSO-E and bilaterally between Fingrid and its neighbouring TSOs.

Network codes

Network codes are part of the European energy policy toolbox, which seeks to safeguard the reliability of electricity supply and to promote competition and emission reductions in the electricity sector. Key players in the preparation of network codes are the European Commission, the European TSOs via their cooperation organisation ENTSO-E and energy regulators via their cooperation agency ACER. The various electricity market parties are also widely consulted in the preparation of network codes.

The network codes have the legislative status of a European regulation, which means that they are directly applicable legislation in the EU member states. As European legislation, network codes take precedence over national legislation. Member States are responsible for the introduction of network codes.

The network codes are divided into three categories: codes for connections, network operation and the electricity market. The goal of the network codes is to create operational criteria for production plants, consumption, and HVDC equipment connected to the main grid and distribution networks.

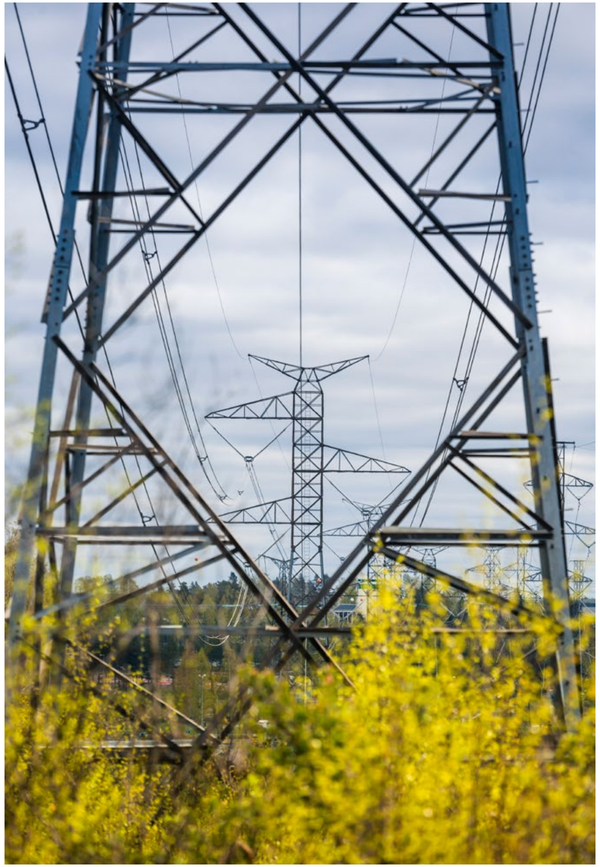
The network codes based on European legislation are:

- Requirements for Generators (RfG)
- Demand Connection Code (DCC)
- High-Voltage Direct Current Connections (HVDC)

and, in addition, a national specification of the technical system requirements for grid energy storage has been prepared for the connection of grid energy storage facilities (SJV2019).

Fingrid has implemented the provisions of the connection codes (RfG and DCC) as part of the Operational Performance Requirements for Power Plants (VJV), Operational Performance Requirements for Consumption (KJV), and General Connection Terms (YLE). High-voltage direct current systems (HVDC) are subject to separate operational performance requirements. The new operational performance requirements were adopted in 2018 and the connection terms in 2017.

If necessary, the technical system requirements referred to above (VJV/KJV/SJV/HVDC) are supple-



mented by instructions that clarify the current requirement base. A more comprehensive update of the requirement documents will take place around 2023. The general connection conditions will be updated in 2021 and, thereafter, they will be updated whenever necessary.

National grid development methods

Main grid planning can be divided into three parts: planning of the main power transmission grid, planning of the regional grid, and planning of connections. At the general level, planning of the main power transmission network means all planning that primarily targets the 400 kV and 220 kV grids. Regional network planning mainly focuses on assessing the development needs for the 110 kV grid. As a result, assessing the need for transformer capacity is mainly within the scope of regional grid planning.

However, the main grid naturally has to be planned as a whole, and the division presented above is only intended as a guideline. In the present operating environment, it will no longer be possible to carry out planning of the main power transmission grid, the regional grid, and connections in isolation; the requirements of each perspective must be taken into consideration when planning the overall entity. At the moment, a lot of large connections are planned. For this reason, connectivity assessments require extensive regional plans at many levels, including plans for the main electricity transmission grid. In addition, alternative plans must be drawn up with an eye to alternative development pathways.

In the long term, vision work is undertaken to prepare for future uncertainties. This work involves analysing trends in transmissions in the main grid under various future scenarios.

Vision work

The grid is always planned as a whole in a future-oriented way. In early 2021, Fingrid published its network vision, which looks ahead to 2035 and 2045, envisioning the development that the main grid will require. The network vision is a view of the grid's long-term development needs based on various future scenarios that describe the structure of electricity generation and consumption. The goal of the network vision is to present the developments in the main power transmission grid that would best serve many different future situations.

The vision is based on a view of future challenges and needs in electricity transmission. Currently, the grid vision is dominated by the transition from fossil fuels to renewable forms of energy, in line with the carbon-neutrality targets of Finland and the European Union. Renewable forms of energy are constantly improving in competitiveness. The system must also be able to respond to transmission needs and changes in generation and consumption in the future.

In order to manage uncertainties in the future, the grid vision reviews a range of scenarios. These are used to specify development pathways and future scenarios, which are drawn up using the broadest possible existing information from inside and outside the company. The goal is to gain an understanding of future transmission needs, the challenges that will affect the main grid, and the kind of world that awaits the company in the future.

Fingrid updates its network vision work every few years. In 2021, the network vision work was opened up for the first time to our stakeholders and customers for comments, and we put their feedback to use when we refined the scenarios that made it into the network vision. For more information about Fingrid's network vision work, see Fingrid's website: Network vision – Fingrid

Planning of the main power transmission grid

The main power transmission grid enables the connection of large power plants and production clusters to the grid, and caters for the power transmission needs between countries and regions. The main power transmission grid includes 400 and 220 kV main grid connections, which are considered important in terms of the Nordic synchronous system.

The entire main grid managed by Fingrid is being developed for the long term. When planning infrastructure solutions with a long-term impact, it is important to assess uncertainties in the operating environment as extensively as possible, and to strive for flexibility, as the grid solutions must also serve the system, as well as possible changing situations and future scenarios. Fingrid aims to develop the main grid in such a way that it enables Finland to achieve its climate-neutrality targets without forming a bottleneck under any likely future scenario.

The factors affecting the planning of the main power transmission grid include:

- Starting points
  - The set requirements
  - The existing system
- Changes in electricity generation
  - Concrete investment decisions
  - Projected generation capacity trends
- Changes in electricity consumption
  - Concrete investment decisions
  - Projected consumption trends
- Changes in electricity transmission via cross-border connections
- Analysable events within the provided framework
- The types of faults or outages that must be prepared for
- Permitted consequences for the analysed events

Planning of the main power transmission grid takes into account the need to reinforce the transmission grid and the technical system requirements. The method used for analysing current and future reinforcement needs for the main power transmission grid includes:

- Determining the starting points, including the relevant development scenarios,
- Analyses of the operational performance needs of the system, including power and energy balance analyses and grid analyses,
- Comparison and evaluation of alternative techno-economic solutions (the economic assessment is based on economic theory).

The process is illustrated in Figure 12, and the steps in the process from design to implementation are shown in Figure 13. Operational performance analyses are performed as an interactive process, in which the results of power and energy balance analyses provide the initial data for grid analyses and vice versa.

Figure 13 illustrates the various phases in the development process. Overall, the lead time for a new transmission line, from the drawing board to the finished line, is 7–10 years for lines within Finland and possibly even longer for cross-border lines. Efforts are made to identify the investments required to address various future development pathways even earlier than this. For example, this is one focus of the network vision and other strategic network planning. It is normal for investment needs to be revised as the process goes on. When planning the main power transmission network, it is also important to examine how the system will work as a whole when the structure of generation and consumption changes. A further question is whether a different range of network technologies will be needed in the future.

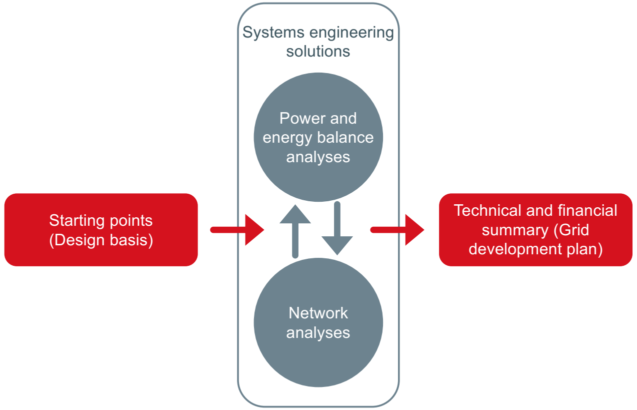


Figure 12. The method for assessing the need to strengthen the main grid

Important assessment criteria in main power transmission grid planning are:

- System security
- Transmission capacity corresponding to transmission requirements
- Benefits for electricity market parties and the operation of the electricity market
- Reducing the risk of electricity shortages
- Changes in transmission losses
- Creating connection opportunities
- Trading in system services

The aim of planning is to improve the transmission capacity so that there is enough of it to ensure that the preconditions are in place for maintaining a single bidding area for electricity trading in Finland (except for the Åland Islands, which are the responsibility of Kraftnät Åland). In addition to thermal capacity, the factors limiting transmission capacity in the main power transmission grid are voltage and angle stability, which must also be taken into consideration in planning. The need for investments in the transmission grid is assessed on the basis of future development scenarios derived from generation, consumption, and grid investment plans. The assessment utilises technical and financial simulations of the transmission capacity and the markets, as well as cost-benefit analyses.

The transmission capacity can be increased by means such as adding new physical connections and investing in series and parallel shunt compensation. Along with the construction of new lines, the capacity of the main power transmission grid can be increased by means of various controls and reactive power compensation solutions. This is because stability is often the limiting factor rather than thermal capacity. New technologies, such as DLR, offer new opportunities to improve the transmission capacity.

System security is taken into account by means of the n–1 criterion when dimensioning the meshed 400 kV main power transmission grid. In all potential planning situations, this means being prepared for any possible individual fault in a main power transmission grid component or power plant, so that this does not cause an electricity transmission outage for consumers or generators.

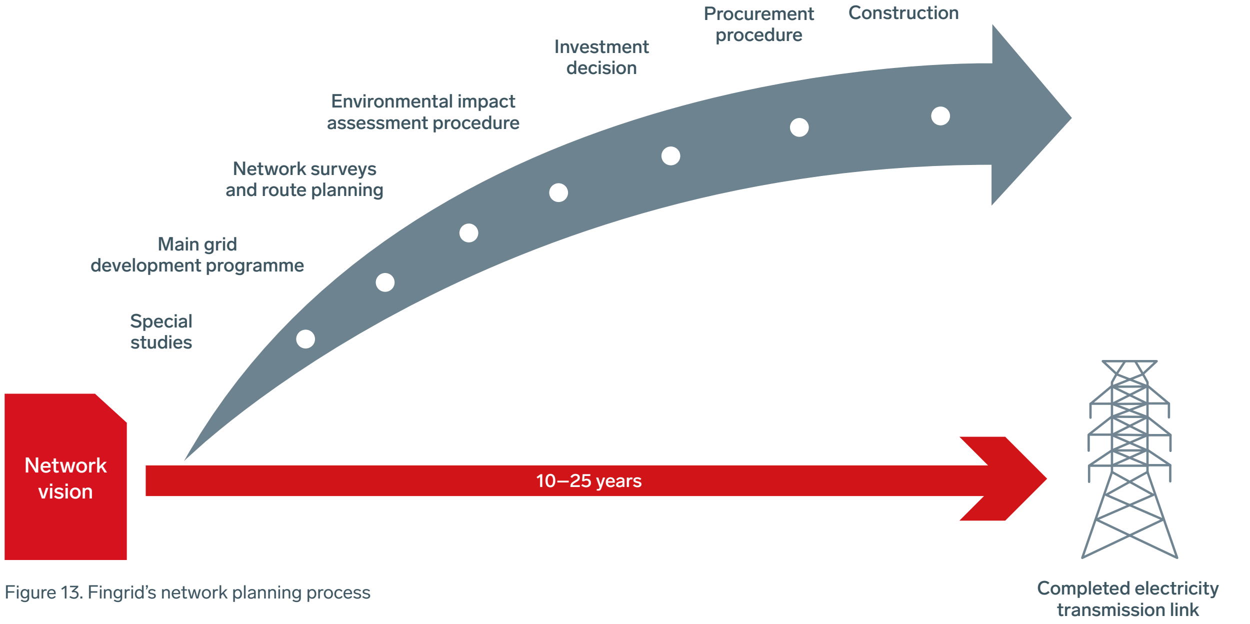


Figure 13. Fingrid's network planning process

Planning of the regional power transmission grid

In its current form, regional grid planning has been done since the early 2000s. For the purposes of regional grid planning, Finland is divided into 12 planning areas, which were formed according to geographical and electrotechnical principles. The regional division is presented in Figure 14. The sufficiency of the transmission capacity in each area is ensured by means of regional plans compiled every 3–5 years. Regional planning focuses particularly on the 110 kV and 220 kV main grid and the 400 kV main power transmission grid that supports it. Due to changes in the operating environment, the number of connecting parties and the sizes of the connections have increased dramatically, so the 400 kV grid has taken on renewed importance in regional network planning. In addition to the main grid, planning takes into account the high-voltage distribution networks owned by other companies, and their development plans and needs.

Starting points for regional grid planning

The starting points for planning are the dimensioning principles. The 110 kV and 220 kV main grid is dimensioned so that the grid can withstand an individual fault without causing a grid overload, voltages falling below the allowed limits, or the fault spreading to other parts of the grid. Dimensioning of the 110 and 220 kV grid is mainly done according to the thermal transmission capacity, short-circuit currents and the allowed voltage reduction. Furthermore, grid stability also limits transmission in Lapland due to the long distances. A regional operational outage caused by an individual fault is permitted in dimensioning of the 110 kV grid.

Dimensioning grid situations vary by planning region. In certain regions, transmissions in the main power transmission grid (400 kV) have a strong effect on the loading of the meshed 110 kV network and result in, for example, losses. Exceptional main grid switching situations or extended grid outages must also be taken into account in extraordinary situations. As a rule, however, the grid is rated to withstand a failure or outage in any of its components. Outages required for maintenance and construction are scheduled to take place during lower transmission needs as far as possible.

With regard to the regional 110 kV grid, dimensioning scenarios can include peak loads on a winter's day, spikes in electricity consumption during winter nights when the volume of hydro power is low, a large generation surplus during the flooding period in the spring, or a large deficit on a summer's day when local power plants are undergoing annual maintenance. As wind power volumes are

1. Lapland
2. Sea Lapland
3. Oulu Region
4. Kainuu
5. Ostrobothnia
6. Central Finland
7. Savo-Karelia
8. Pori and Rauma region
9. Häme
10. Southeast Finland
11. Southwest Finland
12. Uusimaa

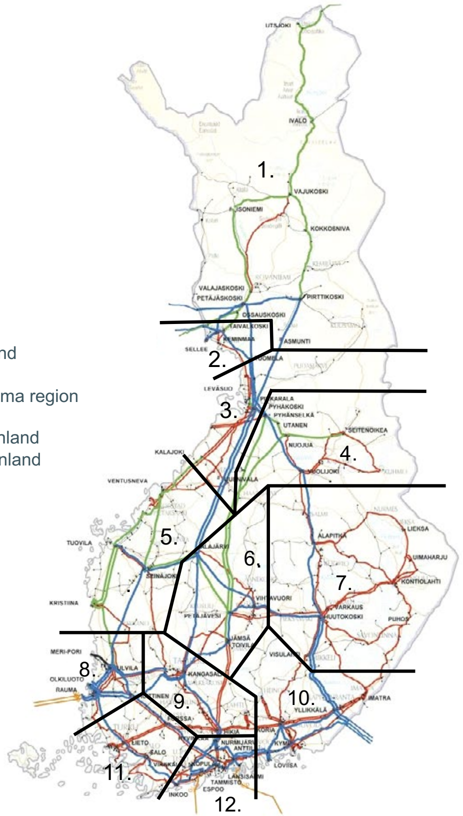


Figure 14. Network planning areas

constantly increasing, this form of energy has become regionally significant and a starting point for the dimensioning of plans. Finland's electricity consumption is traditionally highest during the long, cold winter. On the other hand, more production capacity is also in use during the winter. The heating load in the summer is smaller, but the cooling load is increased. Condensing and back-pressure production is used less in the summer, and power plant revisions are usually performed during the summer, which means that even production plants functioning on a long operating time are out of use. Thus, large power flows in the grid can also occur during the summer. The challenge is the grid's thermal transmission capacity, which is at its lowest during warm weather, because the outdoor temperature has a significant impact on the thermal capacity, especially with regard to transmission lines and transformers.

When calculating the grid transmission capacity, the aim is to model power plant operation as realistically as possible. Wind power, and possibly solar power in the future, pose new and specific challenges with regard to dimensioning the main grid. Wind power generation varies depending on the wind, and it can fluctuate very quickly between zero and the turbine's nominal output, which means that the grid must be dimensioned according to the highest and lowest levels of power generation. The general probability figures specified for wind power as a proportion of generation at different times cannot be used in regional grid planning because variations in weather conditions within the region can be significantly smaller than in Finland as a whole. In Finland, the principle for main grid dimensioning is that neither production nor load is limited in a normal grid situation. As a result, mechanisms to limit wind power generation have not yet been used as a grid planning tool, except in the changeover periods. Hydro power generation can vary dramatically, depending on the hydrological situation, the price of electricity, and the available storage capacity. Industrial back-pressure power is dependent on the industrial processes to which it is related. With regard to district heating power plants producing electricity and heat, the starting point for grid planning is to have them running during peak load situations in the winter. Some of the back-pressure plants are designed so that they can also operate as condensing power plants. This makes it possible to run the plants even when the load is lower. Outages in power plants designed for continuous use have previously been handled as extraordinary situations. Today, it is more difficult to forecast power plant operating patterns because of the recent changes occurring in the electricity market.

Progress of the spatial plan

Grid planning requires group work in which experts from different areas participate in brainstorming and defining the boundary conditions for planning. Figure 15 presents a simplified diagram of the progress of regional planning.

Regional grid planning is based on confidential discussions with electricity generators, large industry, and network operators, and customers' views on the electricity grid development needs in the region. A confidential and open dialogue with actors in the industry is essential with regard to grid planning, as it is possible that even a large industrial facility can be constructed faster than the electricity grid connection to the main grid that it requires. In addition to building out the transmission grid, time must be reserved for dealing with environmental and land use issues and obtaining the necessary permits. The aim of the discussions held with industry and power generators is to survey the possible changes in capacity and the impacts that improving process efficiency may have on consumption or generation.

Electricity consumption and grid load forecasts for regional and distribution grids affect the development of the population and residential areas, service clusters, and SME industry in the area under examination. Grid planning also involves sensitivity analyses related to the trends in loads

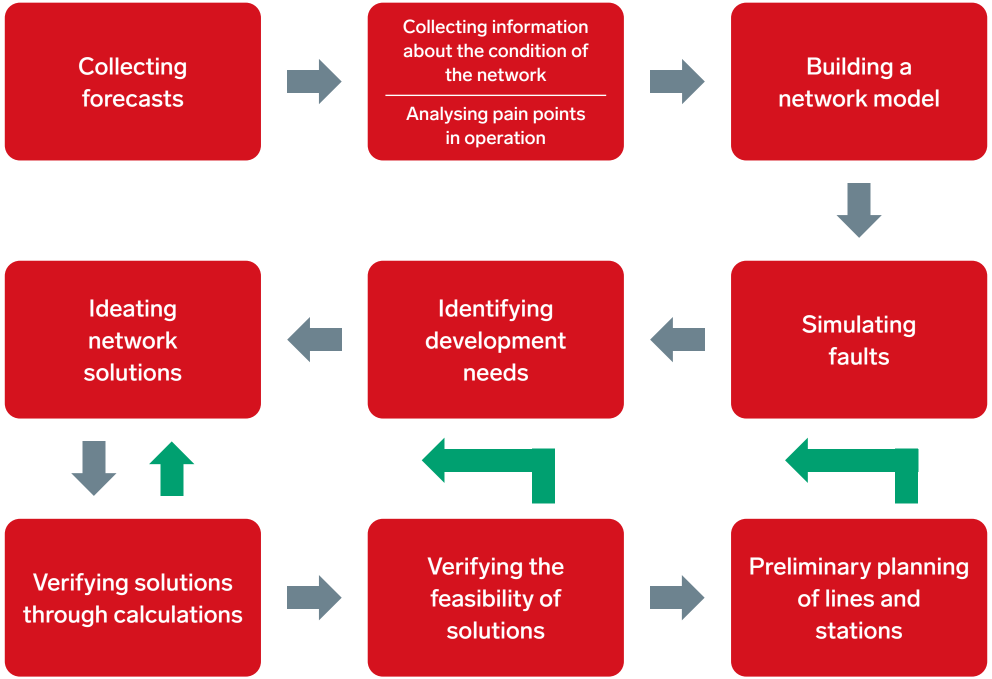


Figure 15. Steps in the regional planning process

Grid planning requires group work in which experts from different areas participate in brainstorming and defining the boundary conditions for planning.

and generation. The actual power levels and transmissions and the operational method of power production can be estimated by analysing measurements from the history database. Industrial expansions and downsizing can occur at a rapid pace, but realisation/investment decisions sometimes take a very long time to happen. As a result, main grid planning must strive for flexible grid development solutions that can cover the transmission needs of electricity consumers and producers without over-investing.

The actual grid planning process begins with a survey of development needs. These needs include managing grid ageing, grid transmission capacity, managing short-circuit currents, electricity quality problems (including voltage variations), and problems related to connection and outage needs.

A suitable simulation program is used to perform power flow calculations in regional grid planning. Based on the forecasts and measurements, consumption and production for each substation are added to the grid model. Grid sufficiency can be assessed by using the power flow software to simulate different faults and extraordinary switching situations. If the grid as such is insufficient in terms of transmission capacity, a group of grid solutions are developed and their sufficiency examined by means of network calculation. Power flow and short-circuit current calculations are often sufficient when planning the 110 and 220 kV grid. Dynamics calculation is performed in extraordinary situations, making it possible to assess the angle and voltage stability of the grid.

Power flow calculations are used to determine the grid load and voltages in situations following a fault and losses. The calculations also take into account bypass circuits after a fault. For example, in Lapland it may be necessary to also perform dynamics analyses in the 220 and 110 kV grid because of the long transmission distances. The 110 kV grid in the Helsinki region is densely meshed and connected to several power production plants, which means that an overly high short-circuit current level can easily become a problem, which has to be limited by, for example, dividing the grid into parts. In other places, the short-circuit current may be too small, in which case rapidly changing or asymmetrical loads cause excessive changes in voltage.

Power flow calculations in regional planning are done using a future grid model, generally for 5, 10 and 15 years from the present. A further aim is to assess possible development directions even farther into the future. Grid development needs in the distant future occasionally influence grid planning and construction in the near future. For example, the placement of substations in the line route plans must take all realistic future scenarios into consideration.

If the grid as such is insufficient in terms of transmission capacity, a group of grid solutions are developed and their feasibility verified by means of network calculation. Finding the best grid solutions generally requires time and group work. Grid solutions strive to optimise investment costs, transmission losses, and environmental impacts, among other things. The aim of planning is to find the best grid solution in terms of economics. Grid solutions aim to cover the existing grid as effectively as possible. A switchyard or transformer substation can be added to a transmission line intersection in order to control transmissions in the area. Post-fault undervoltage can, in turn, be influenced by adding a shunt capacitor to a substation. In addition to conventional network solutions, efforts are made to add new technologies to the system in order to use the existing grid as efficiently as possible. Such technologies include Dynamic Line Rating (DLR), which is discussed in the section on page 93. When a solution for increasing transmission capacity cannot be found in the existing grid structure, transmission capacity can be reinforced by building a new transmission line or replacing an old line with a new one. In certain cases, the transmission line conductors can be changed to those with a larger cross-sectional area or from 1-conductor elements to 2-conductor elements, providing that the tower structures for the transmission line are dimensioned for heavier conductors. One option is the use of high-temperature conductors, which allow for increased transmission capacity without replacing towers. The weakness of special conductors is higher costs and greater transmission losses. However, the transmission line often has to be completely renewed due to its condition.

The land use needs for new substations and transmission lines must be taken into account in conjunction with the regional plan. A new plan must be developed if projects are not possible with regard to land use. Grid investments are not worth doing ahead of schedule unless there is a specific reason to accelerate the schedule (such as arranging transmission outages potentially required by the project). The closer the grid investment is to the need, the easier it is to see what kind of transmission needs will occur in the future, and the more likely it is that the right grid investment is made. Predicting the future is very difficult and becoming more challenging by the day, as the operating environment is evolving so rapidly. For this reason, network plans must be as flexible as possible.

Based on customer feedback, Fingrid has tried to develop the regional planning process in a way that engages customers to a greater extent. The new operating model allows customers to express their needs and comment on the plan in different phases of the planning process. Once a consensus has been reached concerning the grid solution, a summary of the plan is presented to customers in the area.

The grid plan that corresponds to the most probable future scenario is added to Fingrid's main grid investment plan. The grid plans and development plan are updated as the scenarios become clearer.

Connection of new production and consumption to the main grid

The Electricity Market Act stipulates that the transmission system operator has grid development and connection obligations. The grid operator must, upon request and in return for reasonable compensation, connect to the grid any electricity accounting points and electricity generation plants that meet the technical requirements in its area of operation. As the main grid must always meet the system security criteria set for it and, in principle, the entire network must be a uniform bidding area for electricity trading, the requisite network reinforcement measures must be taken before implementing any connections. Fingrid decides upon these before concluding connection agreements. In practice, customers' connection requirements and other changes in generation and consumption require continuous development of the grid as a whole – not just in terms of connections.

Fingrid's connection conditions and process are described on Fingrid's website. The connection point is agreed between the connecting party and Fingrid. The main principle is that the customer pays a fixed connection fee for its connection, while Fingrid handles the changes to the main grid and any grid reinforcement needs. The connection methods are switchgear connections, transmission line connections, and – coming soon under a new pilot project – a connection substation, which is described in more detail in a dedicated section of the document. Connection substations do not provide the main grid with any additional connection capacity, but they increase the system security of the network.

A switchgear connection means connecting to 400, 220, or 110 kV switchgear at a Fingrid substation. For technical reasons, connections with a power rating of 250 MW or more are primarily connected to 400 kV switchgear. For reasons of system security, connections at the 400 kV or 220 kV voltage levels are always implemented at a Fingrid substation.

In Finland, the main grid transmission lines are long, and switchgear stations are far apart due to the geographic transmission distances. As a result, connections to 110 kV transmission lines are also permitted after consideration of the available transmission capacity on the transmission line and other technical conditions. A transmission line connection means connecting a branch line or substation to a 110 kV main grid transmission line via a fixed connection or a switching device. Following the update to the general connection conditions (YLE2021), the maximum permitted nominal power of an individual transformer connecting to a transmission line connection is 40 MVA, and the minimum permitted short-circuit reactance is 48.0 ohms.

Fingrid's general connection terms (YLE), which are a part of the connection agreement, specify the general technical requirements for electric equipment connected to the grid. The connection terms ensure that the connected networks are technically compatible with the grid and specify the rights, responsibilities, and obligations associated with the connection.

Formulating the Fingrid investment plan

The investments to be made in the main grid are listed in the main grid investment plan. The investment plan covers new and replacement investments for the main grid during the next 10 years. Projects end up in the investment plan on the basis of needs specified in the grid plans and maintenance plans. The investment plan is the best estimate of future projects at a given point in time. It specifies the scopes, timetables, and estimated annual costs of investment projects. Fingrid's investment plan is assessed and updated several times a year. If changes occur in the operating environment, the investment plan is updated to correspond to the changed situation.

The investment plan helps in forecasting the sufficiency of internal and external resources and preparing the financial plan. The investment plan does not constitute an investment decision – these are made when the need for a project is realised and the project implementation is about to begin. As the operating environment is difficult to predict, lots of changes may occur at short notice. Consequently, Fingrid's investment plan must be agile and flexibly updated. In addition to the investment plan, alternative solutions are studied and, if necessary, added to the investment plan.

The reporting and updating process for the investment plan has been and will constantly be improved to ensure that Fingrid always has the best possible situational awareness available.

Starting points for the development plan

Fingrid’s main grid and the Finnish electricity transmission system

The Finnish power system consists of power plants and consumers, as well as the main grid, high-voltage distribution networks, and distribution networks, which all connect power plants with consumers. In practice, electricity is transmitted in the main grid directly to major consumers and consumption areas for further distribution. Local transmission to small users takes place in the distribution networks. The power system of Finland is part of the joint-Nordic power system along with the Swedish, Norwegian and eastern Denmark systems. Finland is also connected to the Russian and Estonian systems by HVDC transmission links. The joint-Nordic system is connected to the Central European and Lithuanian systems through HVDC transmission links.

The main grid is the primary electricity transmission network and includes the 400, 220 and 110 kV lines that are most important for electricity transmission as well as substations. According to the Electricity Market Act, Fingrid must designate and publish the transmission lines, substations, and other equipment that belongs to its main grid for the duration of each supervision period, for the purpose of pricing its transmission services. This information must be provided at least nine months before the start of the supervision period. Figure 16 presents Fingrid Oyj’s electricity transmission network.

The main grid serves electricity generators and consumers by enabling a functional electricity market throughout the country, as well as cross-border electricity trading. The majority of electricity consumed in Finland is transmitted via the main grid. Fingrid is responsible for the development, operation and maintenance of the main grid and the promotion of electricity markets. Further tasks involve participating in the operations of ENTSO-E and the detailed preparation of European network codes, as well as cross-border grid planning.

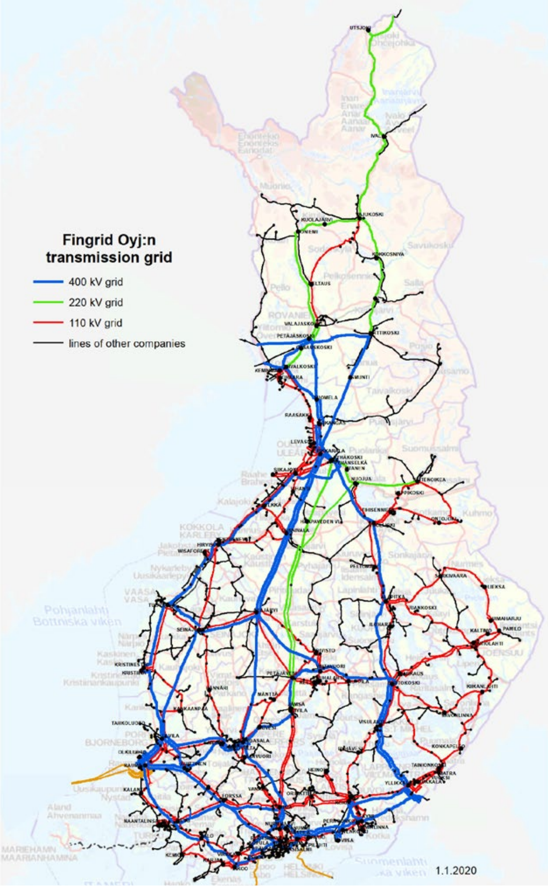


Figure 16. Fingrid Oyj’s electricity transmission network

Life-cycle management in the main grid

The main grid consists of transmission lines and substations, which in turn comprise many different components and structural parts. These parts have different lifetimes with different service and maintenance needs and different lifetimes after which they must, at the latest, be replaced. The only elements of main grid assets that do not age are the user rights to the plots and rights-of-way.

Substations naturally have components of different ages, because substations are seldom built to the final extent all at once. Space is reserved for expansions, which are implemented as needed. Consequently, the age of a substation must be assessed on a component-by-component basis. The age of a transmission line is clearer, although it is also complicated by, for example, changes and additions of conductors. As a general rule, a transmission line clearly has a longer lifespan than a substation. The lifespan expectation for a transmission line is between 35 and 80 years; wooden towers embedded underground have the shortest expectation and steel towers the longest. The expected lifespans of substation components are clearly shorter: between 30 and 60

Transformers	60 yrs	Overvoltage protectors	40 yrs
Switches	40 yrs	Capacitors	40 yrs
Disconnectors	40 yrs	Oil reactors	45 yrs
Instrument transformers	35 yrs	Dry-type reactors	30 yrs

years. In addition, the life cycles of the secondary equipment in substations are considerably shorter than those of the primary equipment. The tables below present the technical service lives of grid components in accordance with the regulatory model.

The Finnish main grid has taken its present form for more than 80 years. The oldest 110 kV transmission lines still in use were built in the 1930s. The majority of the main grid's oldest parts have already been renovated or replaced. However, some very aged transmission lines are still in use. In contrast, the oldest equipment at substations was replaced with new equipment a long time ago. At this time, the average age of the main grid is approximately 26 years. Currently, the average age of transmission lines is 32 years, which is more than 10 years higher than the average age of the high voltage

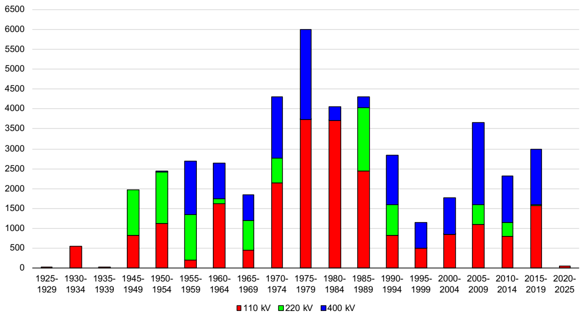


Figure 17. Age distribution of Fingrid's towers

components in substations, which is 18 years. Approximately one-sixth of the total length of transmission lines is more than 50 years old, while less than 5 per cent of the substation equipment is over 40 years old.

As a component nears the end of its lifetime, efforts are made to time its replacement before damage and an increasing number of faults cause problems. In addition to the condition of the equipment, the timing is influenced by many other factors, such as supply possibilities during operational outages and suitable renewal entities. Sometimes a replacement investment can be deliberately delayed. The lifespan can be lengthened with repairs and refurbishments. This allows the most rapidly ageing parts last until a satisfactory renewal time for the entity. A slight decline in the grid's system security due to the delay is permitted. However, operational and personnel safety will not be compromised.

Despite maintenance, not all grid components achieve the normal lifespan, and poor individual parts or component types occasionally have to be renewed earlier. Components that are damaged by faults caused by external reasons must be replaced immediately. As the load increases, a grid part that has become insufficient in terms of technical features may have to be replaced by a stronger component (for example, moving from the 220 kV voltage level to 400 kV). An old device can be replaced with a new one due to superior technical features or lower losses. A component or grid part that becomes unnecessary can be moved to a new location or completely decommissioned. Early replacement investments can also be made for safety and environmental reasons.

A comprehensive and up-to-date grid information system containing historical data for the components is an important tool in terms of optimising lifespans. Such a system makes it possible to take all the data generated during procurement, operation, inspections, and maintenance into consideration in lifespan planning. More of the background information needed in decision-making is gained through international cooperation among transmission system operators. Among other things, cooperation provides experience-based information about component use and faults – information that would otherwise accumulate slowly. New digital condition-monitoring solutions can be used in novel ways to anticipate the onset of faults and thus improve the visibility of the condition of equipment and assets. New technology reduces outages resulting from maintenance operations and faults, and it allocates maintenance work more accurately based on actual needs. This will improve cost efficiency even further.

The aim is to keep the main grid's system security at a good level despite ageing. The timing decisions related to the refurbishment, component repair, lifespan continuation, and replacement investments of an ageing grid play a key role in the cost-effective and high-quality management of the main grid as an asset. An important aspect of maintaining the main grid development plan is close cooperation between maintenance management and grid planning. Main grid maintenance and refurbishment needs obtained by means of condition monitoring and other methods are collected in the network asset management system. These needs are used to define feasible entities that are implemented in the form of maintenance improvements or as a separate, larger refurbishment project.

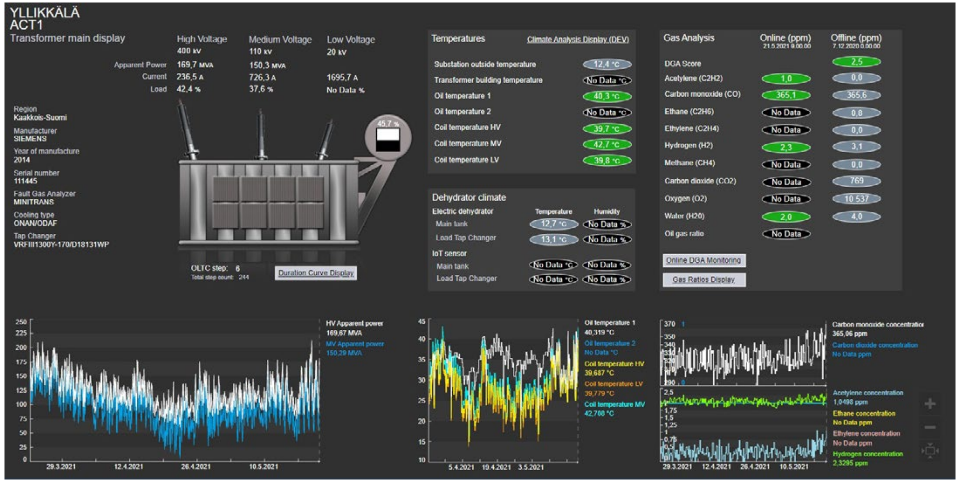


Figure 17. Digital access control – Asset Intelligence display on a transformer

Corporate responsibility (ESG)

Fingrid takes care of people and the environmental impact of its operations, and adheres to good governance, while ensuring a reliable supply of electricity for Finns and the achievement of climate goals. In particular, Fingrid's business promotes the UN's Global Sustainable Development Goals (SDGs) related to climate action, energy, and infrastructure.

Fingrid's operations are meaningful, and its business creates value for Finnish society as a whole. High security of energy supply is critical for the functioning of society as a whole. With affordable and stable grid pricing, Fingrid promotes the competitiveness of Finland. In the energy revolution, Fingrid plays an important role in ensuring that the grid and the electricity market are in shape to support the fight against climate change.

The following sections review the areas of responsibility that have a particular effect on grid planning.

Value created by Fingrid in 2020

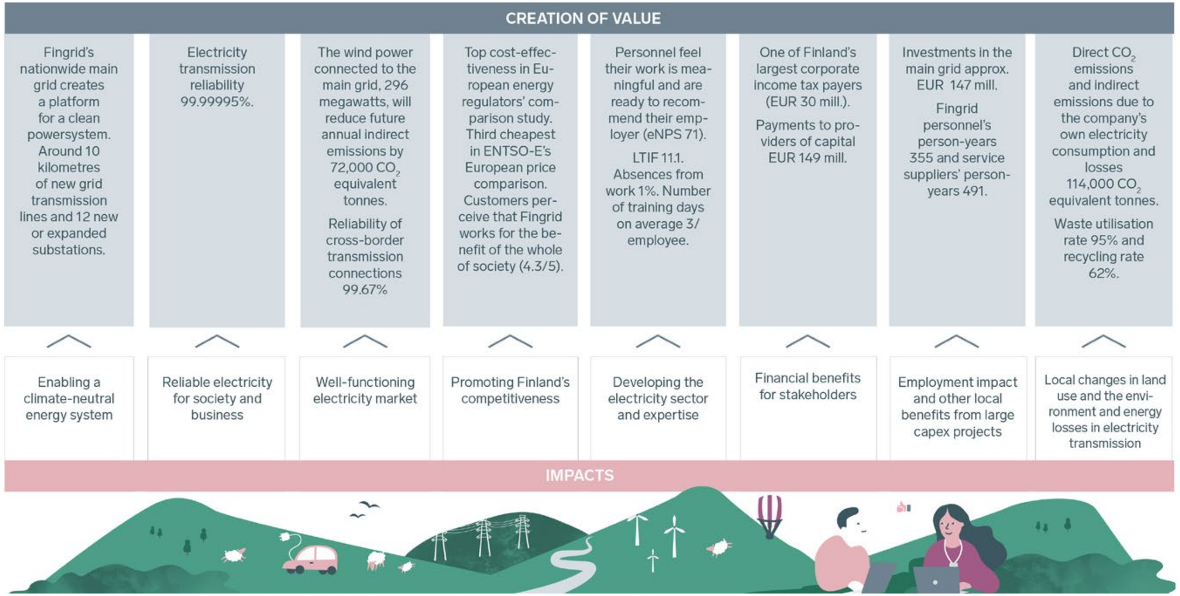


Figure 18. Value created by Fingrid in 2020

Enabling a clean energy system

Effective actions and cooperation are needed to achieve climate objectives. The energy sector plays a key role in combating climate change. The structure of electricity production is changing as the use of renewable energy increases and adjustable fossil production decreases. Wind and solar energy are already profitable without subsidies. Fingrid is committed to operating in accordance with international climate goals and limiting the global temperature increase to 1.5 degrees. Fingrid does not generate electricity itself, but the company promotes efforts to fight climate change by ensuring that clean generation plants can be connected to the electricity system and the electricity can be transferred from generators to consumers.

Fingrid contributes to the fight against climate change by building and maintaining the main grid.

Fingrid contributes to the fight against climate change by building and maintaining the main grid. The change in the production structure of electricity resulting from the fight against climate change will cause changes in the electricity system. An increase in wind and solar power will not only increase the need for additional transmission capacity but also cause a shortage of power, flexibility and system inertia. These are the biggest challenges that Fingrid and the electricity markets must be able to meet in the near future.

Fingrid enables the connection of new energy production to the main grid. Fingrid also ensures the adequacy of system reserves in the future and prepares for a reduction in flexible production capacity, while developing the electricity market for the needs of a low-carbon electricity system. Fingrid's role is to actively present proposals for improving the electricity market model that enable it to stay market-based and clean. Fingrid's operations seek new solutions to ensure that the electricity system works reliably and also finds a market-supported balance between production and demand. Price fluctuations are increasing, which provides business opportunities for flexible production and consumption and for electricity storage technologies.

Other important areas for development with regard to climate change and the environment are reductions in the rate of transmission losses and improvements in energy efficiency.

Environmental considerations

Fingrid's business has a significant positive impact on the environment and climate. The main grid works as the basis for a clean electricity system that is needed to combat climate change. However, the construction, maintenance and operation of the grid also generate a carbon footprint and have an environmental effect. Fingrid ensures that environmental impacts and land use questions are taken into account in the long term. Figure 19 shows Fingrid's most significant environmental impacts.

In 2020, Fingrid's direct carbon dioxide emissions and its indirect carbon dioxide emissions due to electricity consumption and transmission losses amounted to 114,000 tonnes. The majority of the emissions (more than 90 per cent) resulted from electricity generated to compensate for the power losses occurring in electricity transmission. Fingrid minimises losses by keeping the transmission grid's voltage as high as possible and making energy-efficient main grid investments and equipment procurements. Furthermore, the carbon footprint of losses will decrease as the structure of electricity generation changes as a result of the main grid supporting the transfer to clean electricity. In addition to transmission losses, other climate impacts include reserve power plants that are started up during severe disturbances in the power system, and sulphur hexafluoride (SF6), which is a potent greenhouse gas contained in substation equipment. Despite its superb technical properties, SF6 gas is a potent greenhouse gas. For this reason, Fingrid has decided to reduce its use of SF6 gas as the related installations reach the end of their service lives and new technology enables a better alternative. The first GIS switchgear without SF6 gas will be completed in 2022.

Environmental impacts are mitigated at every stage of the main grid's life cycle. Before new transmission lines are built, the transmission capacity of the current network will be utilised to the maximum extent. In the design of new transmission line routes, the starting point is to avoid disrupting important natural sites. Permanent impacts are mainly caused at new tower positions and the border zone of transmission line right-of-ways. In forested areas, the most significant impact is that the right-of-way becomes treeless. The impact of the transmission line projects on humans and the environment is determined by the environmental impact assessment (EIA) procedure required by EIA legislation, or, in the case of projects with minor environmental effects, an environmental study. Consulting landowners is an important aspect in fitting a transmission line into its environment in a way that takes into account the various stakeholders and points of view. In line with our land use and environmental policy, we aim to maintain a successful dialogue with landowners and the neighbours of our transmission lines. For the most part, transmission line projects use existing rights-of-ways in

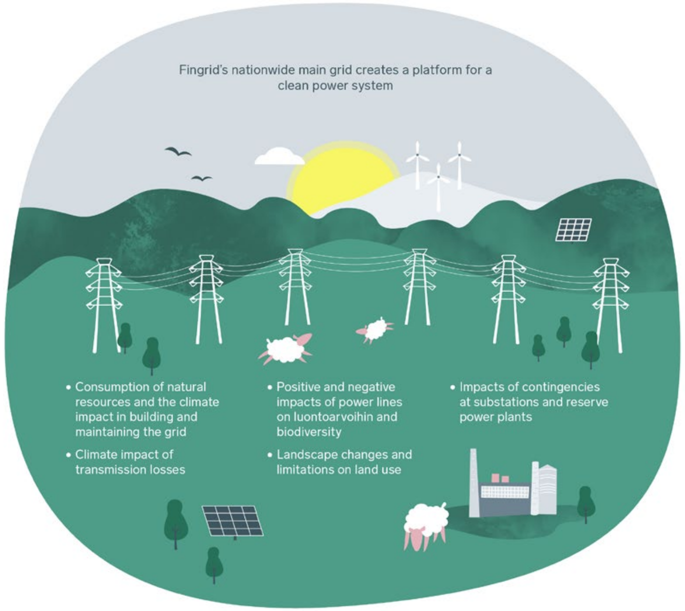


Figure 19. Fingrid's main environmental impacts

accordance with the regional goals for using areas stated in the Land Use and Building Act. Avoiding populated areas and other sensitive sites forms a starting for planning a transmission line that runs in a new right-of-way in the terrain. Fingrid aims to minimise the harmful impacts within the constraints of public interest and the technical and economical boundary conditions. Adverse effects on land use, the landscape, and the environment are also mitigated by tower placement choices and technical solutions (such as placing towers in fields and attaching overhead wire markers to prevent bird strikes).

In addition to electrical safety, the design phase of substations also includes an assessment of other land use in the area and the environmental aspects of the design. The objective is to avoid placing new transformer stations on groundwater areas. The design process assesses the environmental risks caused by the operation and selects the risk management actions best suited for the case, such as alternative chemicals, containment basins and leak monitoring equipment. The emissions of reserve power plants are mitigated by technical solutions, automation and control systems and methods of carrying out trial runs for ensuring that the plant will start up when needed. The landscape effects of new substations and reserve power plants are mitigated as necessary near settlements. The choice of equipment in new substations is subject to noise emission limits. Noise measurements are taken to verify compliance with noise emission limits.

During the construction of a transmission line, we seek to cause as little harm as possible to the environment, landowners, and the nearby population. Nevertheless, the primary concern during construction is to ensure the supply of electricity and the system security of the main grid. Therefore, it might not be always possible to schedule work to take place when its environmental impact is the smallest, such as when the ground is frozen. During the construction of a transmission line, separate instructions are issued to protect the natural values identified during the design of a transmission line. Chemical safety is ensured by proper storage of fuels and lubricants, by having spill response equipment at hand and by instructing workers on safe work practices. Fingrid commits its contractors and service providers to Fingrid's operating methods by using contractual terms and conditions on environmental matters, providing environmental training and conducting environmental audits. Fingrid's goal is to carry out investment projects and maintain the main grid successfully without significant environmental deviations.

The environmental risks of maintenance are managed by, for example, leak alarms and fire extinguishing equipment, as well as training and auditing service providers. Accident preparation measures consist of planning, oil spill response equipment and drills. Only essential chemicals are stored and handled at substations and reserve power plants. The environmental safety of substations and reserve power plants is improved as necessary during refurbishment operations. When structures are dismantled or replaced, the structures and equipment are recycled or otherwise put to good use. Particular attention is paid to the safe handling of chemicals and preparedness for oil spills.

Service providers carrying out transmission line maintenance and processing of vegetation are instructed to take landowners and site-specific natural values into account. Landowners are also notified. In addition to climate change, the deterioration of habitats and the decline in biodiversity are a concern both in Finland and globally. Transmission line right-of-ways are often perceived to have undesirable effects on local land use and landscape. However, the openness and brightness of the rights-of-ways might also have a positive effect on biodiversity. Since transmission line rights-of-ways are regularly cleared, they could act as substitute habitats for species that suffer from the disappearance of meadows or the impact of bog drainage. Fingrid promotes the utilisation of transmission line rights-of-way by offering landowners idea cards on safe ways to utilise rights-of-way for the benefit of nature and people. The company also offers financial support for treating a transmission line right-of-way as a traditional habitat, in the form of a start-up grant and the preparation of a maintenance plan. We also support research on the natural conditions and use of rights-of-way.

At the end of the life cycle of a part of the grid, we deliver the dismantled materials for recycling or other utility use, aiming for maximum re-utilisation of materials. When dismantling the towers, we remove any concrete foundations from yards and fields. In 2020, the total volume of project waste amounted to approximately 10,800 tonnes, of which 95 per cent was reused and 62 per cent was sent for recycling.

Safety

The main grid is constructed to be safe throughout its life cycle. On a general level, the phases of lifecycle of the grid asset are procurement, operation, maintenance, refurbishment and disassembly.

The main grid is designed to be safe in such a way that it meets authoritative regulations and widely used standards and recommendations. Therefore, the main grid is safe for everyone, and it does not cause accidents or health hazards for people who live and work in the vicinity of the network.

For example, the development of load and fault currents is continuously monitored in order to ensure that the grid is reinforced in time, thus avoiding surprising hazardous incidents. Faults and disturbances detected in the power system are analysed to ensure that the protection schemes of grid models are functioning correctly. Safety is measured by examining actual safety incidents and near misses. Assessments of occupational safety take into consideration all incidents affecting Fingrid's personnel and service providers. We monitor reactive and proactive occupational safety metrics. Proactive metrics provide us with information about the work done to enhance occupational safety, while reactive metrics describe occupational safety deviations that have already occurred. Occupational safety is taken into account in the design phase of substations and transmission lines in order to design solutions that support safe implementation.

Maintenance of grid assets ensures that the substations, reserve power plants, and transmission line structures and areas remain safe and conform to electrical safety regulations. Fingrid is obligated to keep the grid in the condition dictated by the electrical safety regulations. The condition of the main grid and the height of the vegetation in transmission line rights-of-way are monitored by regular inspections.

If new structures (such as roads, buildings, ditches, underground cables) are constructed near a transmission line, Fingrid will issue instructions on their construction so that the structures are safe for everyone. Instructions can be obtained by requesting a crossing statement before commencing construction.

Electric and magnetic fields worry people in the vicinity of our transmission lines. Electric and magnetic fields occur all around us, and transmission lines are one source of such fields. Fingrid ensures that the electric and magnetic fields caused by transmission lines remain below the recommended maximum values and has issued a statement on electric and magnetic fields. In 2020, Fingrid published a new brochure on electromagnetic fields and the health effects of such fields. The brochure can be found on Fingrid's website.

Technical choices for the electricity transmission system

This section presents the basic solutions used in Fingrid's network. It also reviews a few relevant technologies that are considered beneficial in the changing operating environment during the review period.

Basic choices

The main grid uses high voltages because of the long transmission distances and in order to reduce the losses that inevitably arise in electricity transmission at high transmission powers. The largest alternating current voltage used in the Finnish main grid is 400 kV. There does not appear to be a need to adopt higher voltage levels in Finland.

The Finnish main grid has primarily been built with air insulation, which means that the substations are installed outdoors and the transmission lines are overhead lines. However, in recent years the use of gas-insulated switching station (GIS) solutions in the main grid has increased. The use of underground cables in the main grid is limited, because they are technically challenging and expensive with the long transmission distances typical in Finland.

Basic electricity transmission technology solutions have remained unchanged for decades and there are no technologies on the horizon that would change the solutions. Finland's main grid is based on overhead lines and alternating current. Electricity transmission in the main grid owned by Fingrid takes place at the 400, 220 and 110 kV voltage levels. Electricity is transmitted between the voltage levels by means of transformers. The nominal power of 400/220 kV and 400/110 kV transformers is typically 400 MVA, and that of 220/110 kV transformers is 100–250 MVA. The main grid still includes transmission lines from the 1930s and substations from the 1970s. The lines now being built can be expected to be in use for at least 60–80 years.

A distinctive feature of the Finnish main grid is long transmission distances. The use of high-voltage alternating current cables in the main grid is mainly limited to the vicinity of substations, and the maximum length of the cables is usually a few hundred metres. More extensive use of cables is not worthwhile due to cost and electrotechnical limitations. When using alternating current, electricity cannot be efficiently transmitted over long distances by cable, especially in the 110–400 kV grid. The transmission capacity of 400 kV overhead lines is 2–3 times higher than the best cables, which means that several parallel cables have to be used to replace overhead lines. The Baltic Sea cross-border transmission connections from Finland to Sweden have been implemented by means of direct current technology, which enables the construction of long cable connections. However, the drawbacks of HVDC transmission links are very high construction costs and lower system security resulting from more complicated technology. The power in such lines is also not regulated automatically according to the grid state, which makes the system more complicated to manage, as every connection must be adjusted individually. It is also expensive and technically difficult to add intermediate stations to HVDC transmission links. For these reasons, HVDC transmission links are not suitable for more extensive use in the Finnish internal main grid.

The thermal capacity of electricity transmission components is limited by warming of the components caused by losses due to resistance. Transmission capacity in the main power transmission grid is often limited by other electrotechnical phenomena, such as power oscillations at power plants following grid faults and the voltage stability of the grid. These limitations can be addressed with advanced technology. For example, series compensation on long 400 kV transmission lines and the Static Var Compensator (SVC) built at Kangasala have significantly increased the transmission capacity and system security of the main power transmission grid without the construction of new transmission lines. Additional stabilising systems at large power plants also make higher transmission capacities possible in the main grid. The world's first wind power plant Power Oscillation Damping (POD) regulating system has been introduced in Lapland. It can effectively dampen power oscillations occurring in the grid. This solution allows the connection of significantly higher production amounts to the grid. Highly accurate measurement devices (PMU) installed on different parts of the Nordic power transmis-

sion network make it possible to continuously monitor the status of the power system (WAMS system) and make detailed analyses of various phenomena in the grid. As information describing the status of the power system increases, the grid can be used in a more efficient manner without compromising system security.

In contrast to many other countries, the so-called transmission line connection is permitted in the 110 kV grid in Finland. This allows cost-effective construction of 110 kV feed-in points to a medium-voltage distribution network. The negative side of a transmission line connection is that when a fault occurs in that transmission line, all of the parties connecting directly to that transmission line suffer an interruption in delivery. In addition to faults, maintenance may cause outages in transmission line connections and the connecting party is responsible for arranging alternate supply. Transmission line connections reduce the transmission capacity reserved for the main purpose of the transmission line, which is to transmit electricity between main grid substations, and the availability of the transmission line.

Fingrid is continuously looking for new methods to solve problems occurring in the transmission grid and to harness the full transmission capacity of the existing grid. New promising technologies include devices to measure transmission line load and devices that can be used to control power distribution between parallel connections. In certain places, this can make it possible to delay investments or even completely eliminate the need for new transmission lines.

Significant changes are in store for substation maintenance management. 400 kV substations have moved to disconnecting circuit breakers, thus eliminating the need for disconnectors. This change has reduced switchgear at 400 kV substation by 50-70%. One weakness of duplex switchgear has been the line and busbar outages required for measurement maintenance of the circuit breakers.

Series and parallel shunt compensation

Electricity is transmitted over long distances in Finland's main grid. For example, the generation plants in Northern Finland are a long way from consumption points in the Helsinki region. When electricity is transmitted on long transmission lines, the transmission capacity is often limited by the voltage stability or the damping of power fluctuations rather than the thermal capacity. Series capacitors have been deployed in Finland's main grid as a cost-effective way of boosting the network's transmission capacity. The capacitors compensate for some of the inductive resistance of the lines. Series compensation can be considered to reduce the network's electrical length, thereby improving both voltage stability and angular stability. Series compensation is used on the long 400 kV transmission links between Northern and Southern Finland and between Finland and Sweden.

The transmission grid below Cross-section Central Finland is highly meshed, and the line lengths are short, so series compensation is not a viable alternative. During times of high wind power output, grid transmissions from north to south may increase significantly. Consequently, voltages decrease on the sections of line that do not have series compensation in Central and Southern Finland. In such a case, the north-to-south transmission capacity can be increased using shunt compensation. Fingrid has chosen to build mechanically switchable capacitor batteries as a shunt compensation solution in several substations. Capacitor batteries are connected to the transformer's 21 kV tertiary busbar, enabling compensation to be implemented cost-effectively. Previously, tertiary busbars have only been used for compensation on the inductive side, but capacitor batteries have allowed the capacitive side of the tertiary busbar to be used to good effect.

Dynamic Line Rating (DLR)

The actual load capacity of a line is highly dependent on the environmental conditions and primarily the prevailing weather. The weather conditions with the greatest effect on the line's load capacity are the wind speed and direction. The outdoor temperature has the next-biggest impact. Other factors have a smaller effect, but the intensity of solar radiation and precipitation have a clear impact.

The traditional way of determining a line's load capacity is to use the Static Line Rating (SLR) method, which assumes that the weather conditions will not change and makes some very conservative assumptions in terms of the load capacity. This leads to a constant and, in principle, very low load capacity, as it is necessary to ensure that the line is not subjected to loads above its design temperature at any point, in practice.

Dynamic Line Rating (DLR) means determining and utilising the actual load capacity of a line. In the conditions prevailing in Finland, it is almost always higher than the SLR, and it is twice as high as the SLR on average. DLR makes it possible to ensure that the line is not overloaded under the conditions in which the actual load capacity is lower than the SLR. Over the years, various companies and other organisations have developed several different methodologies for determining the DLR. DLR is by no means a new technology – commercial DLR systems have been available since the early 1990s. However, network operators have been slow to utilise DLR for a number of reasons.

In recent times, the use of DLR has increased for two main reasons: the increase in the volume of wind power and the development of DLR systems. DLR is highly suitable for use with wind power because, in practice, significant positive correlations have been identified between wind power output and DLR.

DLR calculations usually make use of local weather data supported by various measurements using sensors installed on the line. If measurement sensors are used, the general principle is that the weather data is refined according to a certain logic on the basis of the data received from the sensors, and the actual load capacity of the line is calculated using the standard model (CIGRE/IEEE) based on the weather data.

The DLR is generally calculated as both a real-time value and a forecast value. Forecast values can be calculated for several different forecasting periods and often at several different confidence intervals. Weather forecast data is used to calculate the forecasts, and, depending on the system, it may be possible to account for the prior behaviour of the line on the basis of data from sources such as measurement sensors.

In conclusion, it should be stated that DLR can be used to realise significantly more transmission capacity in situations where the line's load capacity restricts the transmission capacity. However, if a line's load capacity is limited to a value below the DLR, it often comes down to the load capacity of substation equipment. In such cases, it may be necessary to consider whether the load capacity of such equipment could be increased in order to achieve additional transmission capacity. Furthermore, voltage and angular stability can also restrict the transmission capacity.

HVDC connections

High-voltage direct current (HVDC) transmission links can be used to transmit electricity cost-efficiently over long distances. HVDC transmission links are particularly favoured for submarine transmission links or for connecting two networks operating at different frequencies. The very fast regulation capacity of HVDC transmission links can also be used as a frequency containment reserve for the electricity network and for network protection when the transmission link connects two different networks.

There are two submarine HVDC transmission links from Finland to Sweden and two to Estonia. The reliability and availability of the HVDC transmission links between the countries has a highly significant effect on the functioning of the electricity market. For this reason, Fingrid makes major investments in maintaining the cross-border connections, investigating disturbances, and rectifying faults.

The number, duration, and countertrade costs of disturbances have been reduced substantially from the figures seen in the 2013–2015 period, and the situation has now stabilised at an excellent level by international comparison. However, regular maintenance and the replacement of subsystems at defined intervals are essential for ensuring that the connections function reliably throughout their life cycles. Known maintenance tasks are planned and timed so as to minimise the adverse impact on the electricity market.

Fingrid collaborates closely with other HVDC owners and equipment manufacturers to ensure the reliable operation of its systems. Similarly, we examine the need for improvements in existing connections and the development of any new connections. One example of this collaboration is the agreement between Fingrid and Svenska kraftnät made at the start of 2021. The agreement calls for the commencement of the investments necessary to extend the service life of the Fenno-Skan 1 connection by an extra 10 years above the normal 40-year life cycle.

Voltage management

Voltage management in the main grid has changed in recent years due to an increase in the capacitive reactive power fed into the main grid. Capacitive reactive power raises the voltage in the electricity grid. If the voltage is too high, it puts a strain on the equipment and installations connected to the grid and may lead to damage. Fingrid ensures that the voltage in the main grid remains at an acceptable level under all operating conditions.

The increase in reactive power is mainly due to increased underground cabling of distribution networks and the change in the power factor of electricity consumption (for example, lighting) from inductive towards a more capacitive character. Fingrid gradually introduced billing for reactive power at individual connection points from 2017 onwards. This was an effort to reduce the amount of reactive power fed into the main grid and steer compensation equipment investments to places where reactive power arises. Many customers have invested large sums in reactive power compensation, but the volume of reactive power fed into the main grid remains high. Further investments are needed.

To compensate for the reactive power produced by the 400 kV electricity transmission grid, reactors of approx-

imately 60 MVAr in capacity are connected to the 20 kV tertiary windings of the main transformers in the main grid. The transformers are designed so that the reactive power consumed by the reactor mainly flows from the 400 kV electricity network. This allows for a cost-effective compensation solution, as reactors and switching devices rated at 20 kV are much more affordable than equipment rated at a higher voltage. The number of reactors ensures that they can consume the reactive power created in an idling 400 kV grid. In practice, this means one reactor to approximately 100 km of 400 kV transmission line.

In addition, the main grid has some 110 kV parallel capacitors. Due to the increased amount of reactive power fed into the main grid, most of these capacitors are now only used for preventing undervoltage in the aftermath of a fault. In some situations, capacitors are also used to reduce the transmission of reactive power, thereby reducing losses.

Locally, voltage is maintained by power plant generators. Power plants with a capacity of more than 10 MW are obligated to participate in a reactive power reserve. A power plant connected to the 400 kV grid must reserve its entire reactive power capacity to support the voltage in the main grid. A power plant of more than 10 MW capacity connected to other voltage levels must reserve half of their reactive power capacity to support the voltage. The reactive power reserve procedure ensures that the voltages in the grid do not rise or fall too much in the event of a fault in the network or in a power plant. The voltage regulation of power plants in the network automatically reacts to changes in the electricity system's voltage and adjusts the plant's reactive power.

Voltage can also be adjusted between different voltage levels by adjusting the transformer ratio of transformers using tap-changers. If the winding switch is stepped down, the transformed ratio will change so that the voltage on the high voltage side increases, and the voltage on the low voltage side decreases. This also means that reactive power flows from the low voltage side to the high voltage side.

Preparations are also made to cope with deviating circumstances in voltage control on the main grid. In certain predefined situations, it is possible to use the reactive power capacity of SVC devices and DC links to support the voltage. In addition, predetermined lines in the meshed main grid can be disconnected, reducing the amount of reactive charge power. In addition, Fingrid has also studied the use of reserve power plants for voltage regulation.

Digital substations

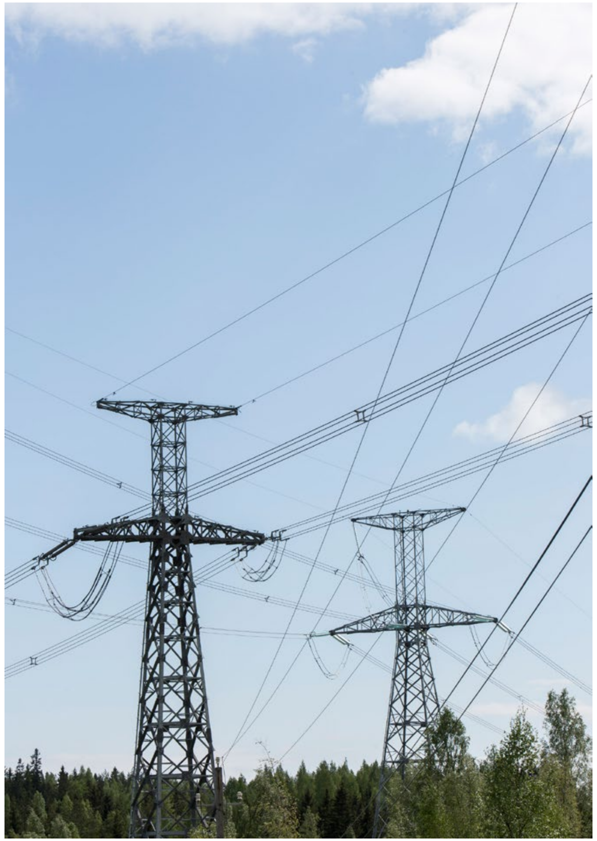
One of Fingrid's strategic projects is a digital substation project, which contains three sub-areas: the digital substation pilot project, a project to develop secondary systems, and digital condition monitoring.

The pilot digital substation will be completed at Pernoonkoski in Kotka in autumn 2021. The project will test traffic based on process buses between high-voltage installations and secondary systems at two 110 kV open-air fields. All measurements and control commands will be sent as signals conforming to the IEC 61850 standard via a fibre-optic network. The most important objectives of the project were to develop in-house expertise, evaluate the benefits of the digital substation, and learn lessons about how the IEC 61850 standard should be applied in practice.

The most significant part of the type approval of the project to develop secondary systems was completed and in use at the start of 2021. Three complete systems from different manufacturers were approved for substations in the main grid. The standardised systems will boost the lead times of substation projects and significantly streamline maintenance.

Digital maintenance management

Digital condition monitoring seeks to enhance the visibility of the condition of substation installations, thereby ensuring system security. It also enhances and modernises maintenance activities, aligning them more closely with needs. Monitoring solutions have been developed through innovation competitions in productive multilateral collaboration with new supplier partners. In 2020, the technical building services of the control centre buildings in substations were included in the monitoring solution in their entirety. In addition, systems developed to detect mechanical and electrical faults in installations in the electricity network were introduced at substations. The deployment of these monitoring solutions will accelerate from the beginning of 2021, with the target of achieving widespread adoption at substations in the coming years. The system also enables existing monitoring solutions to be used more efficiently with regard to factors such as monitoring the condition of transformers and monitoring SF6 gas in switching devices. In terms of digital condition monitoring, there is an active search for partnerships with other applicable TSOs in order to accelerate and diversify the development work.



Utilising generation, storage, and consumption flexibility for the needs of transmission management

As renewable and variable generation and new storage and demand facilities, such as electric transport and smart energy management in buildings, become more widespread, the fluctuations of consumption and generation in the electrical energy system will become more powerful. The market has experienced more substantial fluctuations in the electricity price as a result of this in recent years, as wind power integration has proceeded. In the future, large fluctuations in generation and consumption will have a stronger effect on the need for electricity transmission, which will vary more significantly on a local, regional, and national level.

The integration of wind power alone is likely to alter the need for main grid transmissions in such a way that the greatest need for transmission, whether regionally or nationally, will occur when the wind is strongest. Consequently, the largest relevant transmission periods in terms of dimensioning the electricity transmission capacity may only be a few hours in duration. In practice and for most of the time, the transmission needs may rest at a level that is several dozen per cent lower than the highest transmission needs caused by major weather fronts. Building transmission capacity to cater for the very largest – but potentially short-lived – transmission requirements would not necessarily be cost-effective. At these times, the most efficient way of controlling transmissions may be to adjust local generation, consumption, and storage to keep the transmissions within the limits of the network's capacity.

The solution for transmission management with respect to the potential requirement for new regulation capacity is constituted by new technological solutions for consumption, generation, and storage in the electrical energy system, including the opportunities presented by sector integration. The capacity of these solutions to flexibly control the power extracted from or fed into the network may provide the owners of the resources with the opportunity to benefit from the flexibility that such adjustability enables by offering balancing capacity to service the expanding needs of transmission management. For owners of flexible resources, transmission management may provide a new earning mechanism alongside the price flexibility in the balancing power and reserve markets.

In the OneNet[6] research and development project, which began at the end of 2020, Fingrid is examining the requirements related to how the flexibility enabled by new energy resources can be exploited as one means of addressing the challenges related to transmission management in the main grid. One sub-objective of the project is to examine the transmission management needs that may arise in the network and operation planning, as well as the preconditions for meeting such needs, partly by acquiring flexibility on market terms to address transmission manage-

[6] https://www.fingrid.fi/sivut/ajankohtaista/tiedotteet/2020/fingrid-jatkaa-joustorat-kaisujen-kehitystyota-onenet-joustomarkkinahankkeessa/

ment needs. Based on the results of the study, the aim is to complete a preliminary assessment of the needs and opportunities for meeting such needs and managing the related uncertainties by acquiring flexibility from consumption, storage, and generation facilities through means such as flexibility auctions. The project will also examine the potential added value of flexible connection agreements to promote the connection of new energy resources to the grid – for example, in situations in which network reinforcements are not yet complete due to new investments and, therefore, would delay connection to the network. If the studies indicate that flexibility auctions or flexible connection agreements would be promising methods for ensuring that main grid transmissions remain within the limits of the built transmission capacity when transmission needs reach momentary peaks, preparations have been made to pilot the methods as part of the OneNet project in 2023.

Cost-effective connection substations

More than half of the connections to the main grid have been implemented as 110 kV connections along the transmission line. This is a low-cost method, but any faults in the trunk line and branch lines of the main grid will always cause an outage to all parties connected to the transmission line. Although permanent line faults in the 110 kV network are very rare, transient faults (caused, for example, by thunderstorms), occur fairly often. A transient fault disappears from the transmission line when the line is turned off briefly (approx. 0.7 seconds). However, even a short power cut causes damage to electricity consumers, particularly in industry. The longer the trunk line and the branch lines connected to it, the more disturbances will occur along the line, triggering outages. The number of maintenance outages will also increase. The most effective way to reduce the number of outages and the resulting problems is to divide the main grid into parts by building a main grid substation along the transmission line. Roughly estimated, a switchyard constructed halfway along a transmission line reduces outage problems by 50%, and if long branch lines on the transmission line are connected to the new switchyard, the problems are reduced even more.

Substations of the main grid often serve major cities and industry and are a significant part of the overall electricity transmission system. Therefore, the main grid substations have been constructed to have extremely high system security. However, system security is expensive. Fingrid has investigated the construction of substations on the transmission line in the past, but the costs of the substations were found to exceed the benefits. Fingrid is now developing a new, cost-efficient connection substation, and the first pilot projects are now starting. Fingrid arranged a brainstorming challenge for its employees, customers, and contractors. The result was a working concept. The expandability, system security, and bypass circuit possibilities of the new substation were not as good as for conventional switchgear. However, the construction costs can be up to 50% lower, and the substation meets the design goal superbly, as it improves the system security of transmission line connections. Substations have also been designed to enable bypass circuits for maintenance outages in the distribution network and to connect wind farms to the network in an inexpensive way. The first pilot substations will probably be implemented in 2023.

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