Draft of the development plan

Main grid development plan 2024–2033

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Summary

Developing the main grid to meet the needs of customers and society is one of Fingrid's core tasks. Continuous development of the main grid ensures that the electricity transmission grid and the entire electricity system fulfil their requirements in a changing operating environment. The specific objectives of the grid investments proposed in the development plan are to lay the foundations for Finland's competitiveness in investments in clean energy and industrial investments that use clean energy and enable Finland to reach its carbon neutrality targets by 2035.

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 the grid and connection plans that Fingrid prepares with its customers and the need to strengthen electricity transmission between countries and regions. The plan has been coordinated with the European Union's Ten-Year Network Development Plan (TYNDP), including the plan for the Baltic Sea region.

The preparation of the main 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 describes how, and with which 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 curbing climate change. A clean energy system creates considerable opportunities for Finland, as electricity-intensive industrial investments, such as hydrogen and electric fuel production, are increasingly made in Finland. The main grid will require significant reinforcements as the electricity production structure changes to reduce emissions and society consumes more electricity. Investments in the main grid enable the transition to a clean electricity system and contribute to safeguarding the vital functions of society. The increase in clean electricity production, significant industrial investments, a decrease in the amount of production that can be readily regulated, the geographic location of new production facilities in the main grid, and the pace of electrification in society are key aspects of the development of the main grid.

As the amount of weather-dependent electricity production increases, the power system will experience occasional shortages of power and transmission capacity. In such cases, it will be highly beneficial if electricity consumption can be flexible. Indeed, there are increasing economic incentives for demand-side management as the electricity price becomes more volatile. For example, when there is plenty of wind power production, green hydrogen and other clean electric fuels can be produced relatively cheaply. Conversely, when electricity production is low, electric fuel industries and, for example, electric vehicles offer the potential for flexibility.

As the amount of traditional synchronous electricity production decreases, the adequacy of inertia and short-circuit power in the energy system will challenge the operation of the main grid. New methods for resolving these problems are either already available or under development. The change in the electricity production structure also presents a challenge for transmission capacity in the main grid. Various solutions for supporting the grid voltage and monitoring the current-carrying capacity of transmission lines in real time are now being deployed to enable transmission links to be utilised at full capacity, and more solutions are forthcoming.

Fingrid endeavours to prepare for an unpredictable future by using scenarios to plan the development of the main grid. The adequacy of the grid is tested against different scenarios to identify the network solutions that correspond to various future requirements. In other regards, Fingrid pays close attention to the development of projects and factors that, on their own, could trigger the need to reinforce the main grid. The most critical factors currently being monitored are wind power projects, the progress and geographical location of consumption concentrations and investments resulting from electrification, as well as the pace of electrification in transport and industry.

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Main grid planning process

Main grid planning is a continuous process for which Fingrid collects initial data from different sources. By analysing grid sufficiency based on the initial 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 around 120 substations, which connect grids in neighbouring countries and production plants and major consumption sites located in different parts of Finland to the power system.

Main grid planning encompasses planning to meet the needs of the 400- and 220-kilovolt (kV) main transmission grid, planning related to the development of various regions, and planning of connections. Connection planning increasingly spurs the need to verify the adequacy of the grid over a wider area as connection powers rise.

The main transmission grid enables large power plants and production and consumption clusters to be connected to the grid and caters for the electricity transmission needs between countries and regions. The transformer substations supplying the 110 kV main grid and high-voltage distribution networks are connected to the power system via the main transmission network. The needs of the electricity market determine the transmission needs between countries and regions, and modelling the cross-border electricity market is an important tool in planning the main grid.

The development of electricity networks in different regions is planned in collaboration with customers in the regions. The plans are reconciled with the development plans for transmission requirements between countries and regions. Connections are planned bilaterally with customers, and larger network plans and the forecasted development of network transmission capacity are also taken into account in this regard.

The starting points in the grid development process are electricity consumption and production forecasts and the condition of the grid. Confidential dialogue between Fingrid and its customers plays a key role, involving discussions of the effects and needs of customers' plans on the main grid. A record number of new connections is currently in the planning stage, including some very large projects that call for extensive connectivity feasibility surveys at the main transmission network level. International co-operation on network planning is 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. Regional planning groups also publish regional network development plans focusing on the development of cross-border transmission capacity and connections between price areas. In addition, a Nordic grid plan focusing on the challenges of the Nordic synchronous area and individual cross-border transmission projects 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 ten years, Fingrid is planning to invest even more – approximately EUR 4 billion, averaging EUR 400 million per year. For comparison, Fingrid's annual depreciation previously stood around EUR 100 million, but it will increase in the future. Over the next 10 years, Fingrid's planned main grid investments will involve developing cross-border connections and Finland's internal main transmission grid, grid connections for new electricity production and industry, and the modernisation and refurbishment of the existing grid. The number of connection enquiries has been climbing in recent times with respect to wind and solar power and, in particular, industrial projects related to emission-free energy and electricity storage.

Fingrid seeks to cost-effectively secure reliable electricity transmission for customers and society and shape the clean, market-oriented power system of the future. The specific objectives of the grid investments proposed in the development plan are to lay the foundations for Finland's competitiveness in investments in clean energy and industrial investments that use clean energy and enable Finland to reach its carbon neutrality targets by 2035. If this ambitious target is to be achieved, industry, transport and other forms of consumption must switch to energy sources that do not generate climate emissions and, correspondingly, clean energy production must increase. Rapid progress is being made on both counts. Fingrid has invested and is preparing to invest more in the main grid than ever before to facilitate the energy revolution and ensure sufficient transmission capacity, both within Finland and at cross-border connections. In order to respond to rapidly changing needs, Fingrid maintains a flexible, long-term investment plan, which enables electricity markets to operate in the future.

The greatest need for development will be in increasing the transmission capacity between centres of production and consumption and developing cross-border connections. As the electricity production of the combined heat and power plants in Southern Finland decreases and the consumption of electricity increases, the electricity 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. In addition, a third submarine cable to Estonia

Fingrid maintains a flexible and long-term investment plan.

will increase the transmission needs. The most pressing need in the main grid is to increase the transmission capacity between the north and the south and from the west coast to the south.

The main grid development plan offers the best current insight into Fingrid's future grid reinforcements. The plan is updated in a continuous process as the operating environment evolves. The development plan contains some uncertainty related to new electricity consumption and the locations and schedules of new power plants. Fingrid works closely with its customers and other stakeholders to ensure the plans serve their needs as well as possible and projects are completed on time.

02

Introduction

The power system of Finland is facing the greatest change in its history. The transition from traditional forms of electricity production to climate-neutral alternatives is an absolute requirement for achieving Finland's climate targets and maintaining the viability of the planet. At the same time, increasing clean energy production in Finland enables entirely new industrial sectors to arise in Finland. Finland is now among the most attractive places in the world to invest in industries that use clean energy, such as the production and exploitation of hydrogen and other clean electric fuels. The pace of change is remarkably high, and the transition to a clean electricity system in Finland requires significant investments in the electricity production and consumption structure, electricity storage and flexibility solutions, and a record rate of development of the main grid.

Development of the main grid is one of the basic tasks of Fingrid, 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

must be proactively developed as an overall entity to meet the needs of customers and society. The need for grid reinforcement arises 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.

Development of the main grid is one of the basic tasks of Fingrid, the company responsible for the electricity system in Finland.

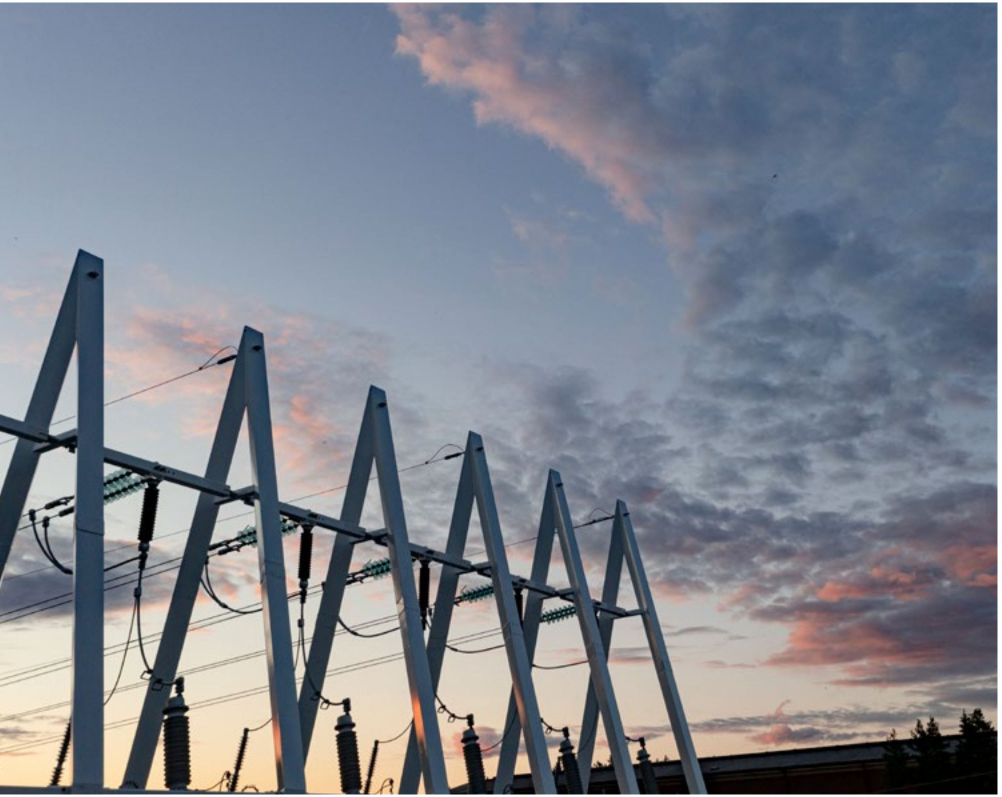
This development plan presents Fingrid's key main grid development measures for the next 10 years. The development plan is based on regional plans compiled in cooperation with electricity transmission customers and the other European transmission system operators. The plan is aligned with the development plan for the Baltic Sea region, as well as the Ten-Year Network Development Plan (TYNDP) covering the entire European Union. The planned projects are based on various forecasts and assumptions about the future. These may change over time, which means that the implementation and timelines of the planned investments may change as well. 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.

03

Main grid development based on Finland's competitiveness and achievement of climate goals

The transformation of the energy sector will play a key role in climate change mitigation. The transition to clean energy is essential for reducing climate emissions, and it also presents a significant opportunity for Finnish society. Finland is among the most attractive places to invest as the world moves towards emission-free energy sources and fuels.

The geographical conditions, societal support and strong power system have enabled Finland to welcome a record number of wind and solar power projects. Approximately 2,000 MW of clean electricity production capacity is expected to be built in Finland every year over the next decade. A total of 2,430 MW of new wind power was built in Finland in 2022. As clean electricity production increases, there will be further opportunities for green industrial investments.



Replacing industrial processes with ones based on electricity from emission-free energy sources and fuels refined using clean electricity, such as hydrogen, will require a huge amount of new electricity production capacity. For example, replacing the fossil energy consumed by one steel mill with hydrogen produced using electricity could require almost as much electrical energy as a nuclear power plant can produce.

Finland and the other Nordic countries are among the best countries for building clean electricity production capacity thanks to their geography, existing clean balancing power (hydroelectric power) and strong power system. Clean electricity can not only be used for direct electricity consumption; it can also be used to make clean electric fuels. Surplus electricity can be used to produce hydrogen and other clean fuels, which could also be export products to satisfy the needs of European industry. Demand for such fuels is expected to be very high as the energy revolution progresses.

In addition to Finland's competitiveness potential, the development of the main grid focuses on reconciling biodiversity with climate change mitigation and ensuring the reliability of the power system. These are also a key aspect of Fingrid's sustainable operations and corporate responsibility. Fingrid's key societal and statutory duty and responsibility for the power system must be taken into account while mitigating climate change and biodiversity loss.

A strong main grid is the basis for the energy revolution

The price and availability of clean electricity are key factors that will influence the operating environment of electricity-intensive industries in the future. In addition, high security of supply in the transmission and distribution of electricity is a prerequisite for the consumption and production of electricity. Due to its high onshore and offshore wind potential, Finland is in an excellent position to compete for investments in the sector. In addition to these, Nordic hydroelectric power, nuclear power and bioenergy are resources that not all of Finland's competitors have at their disposal. Finland also has significant solar power potential, especially in terms of the land area available.

Similarly, in many Central European countries, the further construction of onshore wind power is difficult, the share of nuclear power is small or nuclear power is being abandoned, and the share of hydroelectric power is low. In addition, many European countries have a substantially higher share of fossil-based production in their electricity and energy systems than Finland, so a larger proportion of renewable energy construction goes towards replacing this share.

Based on wind and solar power enquiries in Finland, the estimated production potential is over 15 per cent of the total EU wind and solar power potential, using figures derived from the TYNDP2022 scenarios as the EU benchmark. Correspondingly, Finland accounts for just over 3% of the EU's current electricity consumption. For Finland, the potential of wind and solar power is many times higher than the need for electricity and hydrogen, which is not common in Europe, based on the TYNDP2022 scenarios. In the long term, many EU countries need clean imported electricity, imported hydrogen, or imported products made from these, and Finland, as an EU country, is well placed to produce and export these to other parts of Europe.

Enabling a carbon-neutral society

Fingrid's business has a substantially positive climate impact, as the company's positive carbon handprint is larger than the negative carbon footprint arising from its operations. A positive carbon handprint arises when Fingrid strengthens the main grid to cater for the needs of clean electricity production and connects clean production to the main grid, which indirectly reduces greenhouse gas emissions and enables the transition towards a clean electricity system in line with Finland's climate targets.

Fingrid is committed to operating in accordance with international climate goals to limit the global temperature increase to 1.5 degrees. Fingrid does not produce any electricity, but it promotes climate change mitigation by connecting clean production to the power system and transmitting electricity from producers to consumers. Connecting new, emission-free electricity production and consumption facilities to the electricity system requires a stronger main grid. The negative impacts on nature and carbon footprint arising from the greenhouse gas emissions of investments are reduced in accordance with Fingrid's land use and environmental policy.

The 1,940 megawatts of wind power projects connected to Fingrid's main grid in 2022 alone will indirectly help to avoid an equivalent of 357,000 tonnes of CO2-equivalent emissions every year. Last year, connection agreements were made with Fingrid for approximately 770 megawatts of wind power production. At present, the total output of the production projects for which Fingrid has received connection enquiries is as high as 270,000 MW. When future projects are realised, they will have a significantly positive climate impact.

In addition to connecting emission-free electricity production and consumption facilities to the grid, Fingrid's other important areas for development in terms of climate change and the environment are reducing the carbon dioxide emission impact of power losses arising during transmission and improving the energy efficiency of the company's operations. A further aim is to achieve the highest possible recycling rate for decommissioned materials on worksites. Key considerations in transmission line rights-of-way include protecting nature, supporting biodiversity and mitigating the land use and landscape impacts.

Fingrid is committed to operating in accordance with international climate goals to limit the global temperature increase to 1.5 degrees.

Strong system security in the main grid as the energy transition proceeds

Climate change mitigation and progress towards climate goals must not jeopardise the reliability of the power system. A reliable main grid is a prerequisite for a functioning society and a source of competitiveness for Finland. Fingrid transmits electricity reliably and securely while ensuring that electricity consumption and production remain in balance.

The electricity produced by power plants connected to the main grid is transmitted to main grid customers reliably and with high quality. The electricity transmission reliability rate is maintained and monitored constantly. The transmission reliability rate in the main grid was 99.99993% in 2022. The average outage time at main grid connecting points due to disturbances in Fingrid's network was 4.7 minutes.

The main grid is planned and operated in such a way that no individual fault can lead to a disturbance spreading throughout the main grid. In the event of a nationwide blackout, the economic harm to customers and society would be substantial – in the region of EUR 100 million per hour. This figure demonstrates the importance of Fingrid's success in its core duties.

04

Fingrid's ten-year main grid development plan

Developing the main grid transmission capacity

Fingrid seeks to cost-effectively secure reliable electricity for customers and society and develop the clean, market-oriented power system of the future. Fingrid's investments in the main grid will enable the achievement of climate goals and industrial investments relying on clean energy to create wellbeing. A special objective of the grid investments specified in the development plan is to lay the foundations for Finland's competitiveness and achievement of its target to become carbon neutral by 2035.

Electricity production is increasingly clustered in northern and Central Finland, as well as the western parts of the country. Stronger north-to-south transmission links are required to transmit this electricity to consumption centres in Southern Finland. Transmissions from the west coast to the south are also increasing and may become even more production-oriented as offshore wind power develops. The electricity deficit in Southern Finland is increasing as the electricity production of combined heat and power plants decreases and electricity consumption increases. This deficit will be offset by wind power from the north and the west, and imports, especially from Northern Sweden. As electricity production increases, Finland will become self-sufficient in electrical energy and transmit more electricity to its neighbouring countries. As the amount of weather-dependent electricity production rises, investments in cross-border lines will become increasingly important for balancing the system.

The north–south transmission capacity is limited by two cross-sections defined on electrotechnical bases: Cross-section Central Finland and Cross-section Kemi-Oulujoki. Wind power development has also introduced a new cross-section that limits the transmission capacity to the west coast.

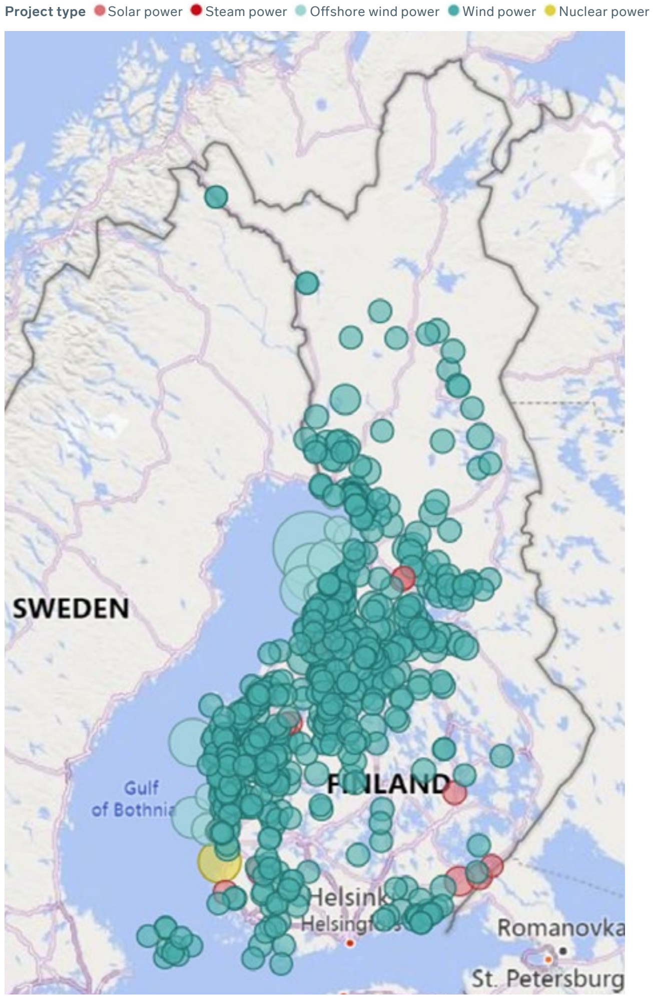
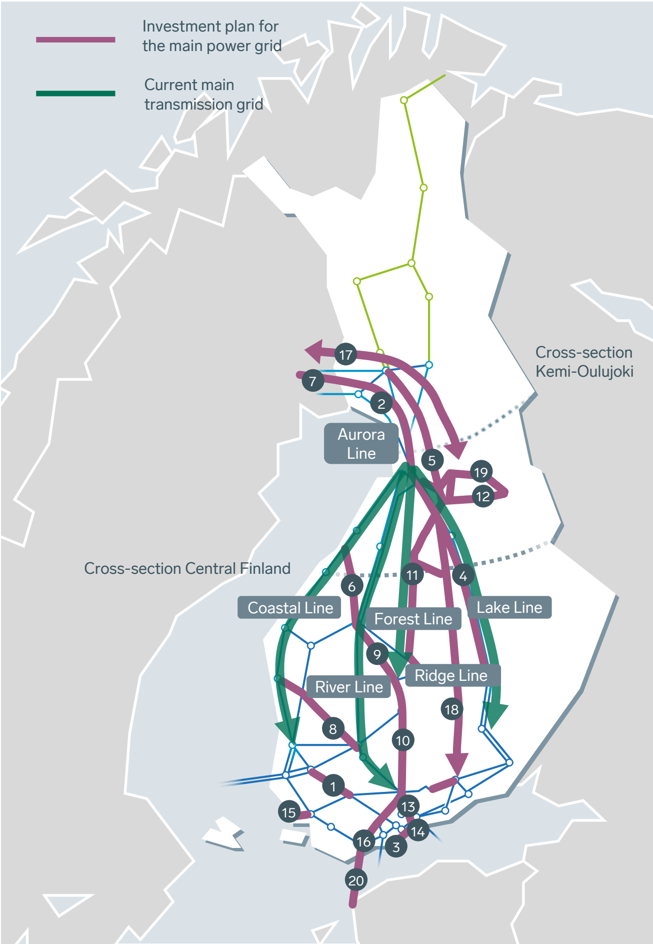


Figure 1. Locations of public electricity production projects in Finland.



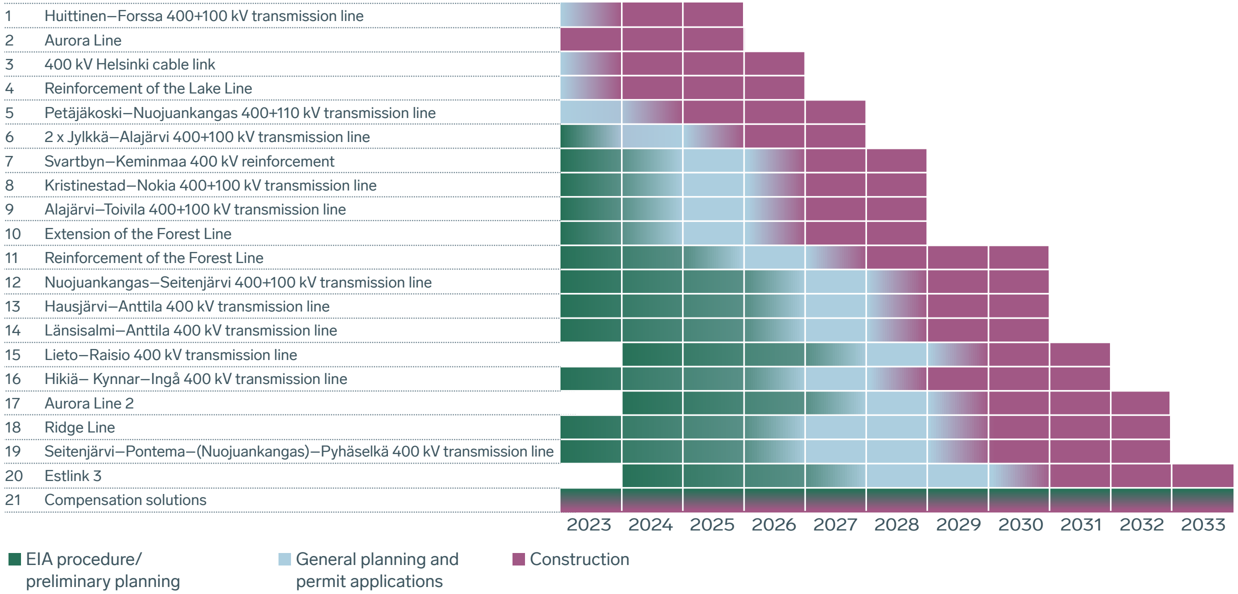


Figure 2. Main grid development plan with respect to the main transmission grid. The new 400 kV connections are shown in purple.

Cross-section Central Finland splits the country from Kokkola via north Iisalmi to the east. The northern region is dominated by hydroelectric and wind power, and there is a surplus of produced electricity. The southern region is dominated by nuclear 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. Four 400 kV transmission corridors pass through the cross-section from Oulu to the south: the Coastal Line, the River Line, the Forest Line and the Lake Line. A new 400 kV transmission line (transmission line 4 in Figure 2) is under construction from Vaala to Joroinen to reinforce the Lake Line. The new line will be completed in 2026.

Cross-section Kemi–Oulujoki divides the northern region into areas north and south of the River Ii. At present, three 400 kV transmission lines pass through the cross-section. A fourth line (the Aurora Line) is under construction from Muhos via Tornio to Sweden (transmission line 2 in Figure 2). The Aurora Line will be completed in 2025.

A cross-section has arisen on the west coast due to the electricity consumption and production facilities connected to the Coastal Line and, in particular, the transmission connections required by wind power plants to transmit electricity from the west coast to the north and south.

The following section examines the development plan for the main transmission grid in more detail in chronological order.

Reinforcements at Cross-section Central Finland

Approximately 2,000 MW of wind power is expected to be built in Finland every year for the next 10 years. A large part of this new capacity will be on the west coast, in Sea Lapland, in North Ostrobothnia and in Kainuu. Electricity consumption is concentrated in Southern Finland, so additional transmission capacity is required between production and consumption facilities.

The transmission capacity through Cross-section Central Finland is currently constrained by the quality of the voltage in the grid south of the cross-section, as well as post-fault voltage stability. Building new transmission lines is one way of increasing the transmission capacity. However, a quick, cost-effective and environmentally-friendly alternative is to deploy shunt compensation, which improves voltage support. Shunt compensation will be implemented at several substations by adding capacitors at the 20 kV and 400 kV voltage levels by the end of 2024. The next investment to raise the transmission capacity through Cross-section Central Finland will be the reinforcement of the Lake Line. A new 400 kV transmission line route will run south from the Nuojuankangas substation in Vaala to the Huutokoski substation in Joroinen (transmission line 4 in Figure 2). The transmission line is under construction and is due for completion in 2026.

In the future, the present capacity of the Coastal Line on the west coast will not be sufficient to transmit all the electricity production planned for the west coast, especially the electricity from wind power, away from the area. The new 400 kV Jylkkä–Alajärvi–Toivila transmission line connection will be needed to increase the electricity transmission capacity and reinforce the western cross-section and Cross-section Central Finland. The first section of the connection will be built from the Jylkkä substation in Kalajoki to Alajärvi by 2027 (transmission line 6 in Figure 2). It will then be extended from Alajärvi to Toivila (transmission line 9 in Figure 2) in 2028. The Jylkkä–Alajärvi section is designed with two circuits. This solution ensures that wind power can be connected to the grid in the future.

The transmission lines running between the north and south must also be strengthened from the Jyväskylä latitude towards consumption centres in the south. The Forest Line will be extended in 2028 from the Toivila substation in Jämsä to the Hikiä substation in Hausjärvi (transmission line 10 in Figure 2). The connection is planned with two transmission lines, and it will be constructed in place of the old 220 kV structural transmission lines. The final scope of the connection will be decided when there more information is available about the production and consumption projects needing transmission capacity.

Towards the end of the planning period, it will become necessary to further strengthen the Forest Line to increase the north–south transmission capacity. The planned transmission line route will run from the Nuojuankangas substation in Vaala to Central Finland (transmission line 11 in Figure 2). The new 400 kV transmission line is planned for commissioning in 2030.

The Ridge Line, a new 400 kV connection linking the Höyttikangas substation in Kajaani and the Pysäysperä substation in Haapajärvi to Southern Finland via Pyhäjärvi (transmission line 18 in Figure 2), is being planned to enable the increasing volume of electricity produced by wind power to be transmitted from the Kainuu, North Ostrobothnia and North Savo regions to consumers in the south. The transmission line is planned for completion in 2032.

Following the investments due for completion from 2024 to 2033, the number of 400 kV transmission lines along the north–south axis will increase from the current five to 11.

Reinforcements at Cross-section Kemi–Oulujoki
The current-carrying capacity of transmission lines is highly dependent on environmental conditions, such as the prevailing temperature and the wind speed. By determining the current-carrying capacity of a transmission line in real time, it is possible to utilise the transmission capacity in full on connections where the current-carrying capacity is constrained by thermal factors, i.e., the loads occurring due to the heating of transmission lines. This technique is known as Dynamic Line Rating (DLR), and the capabilities to use it have been built on the transmission lines going through Cross-section Kemi–Oulujoki. The technique is a cost-effective and environmentally-friendly way of enabling the transmission capacity at the cross-section to be utilised in full.

Cross-section Kemi–Oulujoki will be strengthened following the construction of the Aurora Line (transmission line 2 in Figure 2) in 2024. The new cross-border line will extend from Sweden to Muhos, as far as the Pyhänselkä substation. It will be completed in full in 2025.

Fingrid currently expects a large amount of wind power to be built north of the River Ii in the next 10 years. Connecting wind power to the main grid requires additional strengthening at Cross-section Kemi–Oulujoki. A transmission line from the Petäjäskoski substation in Rovaniemi to the Nuojuankangas substation in Vaala (transmission line 7 in Figure 2) will be completed in 2027, after the Lake Line is reinforced. Additional capacity will also be required as the electricity import capacity from Sweden to Finland increases after the second Aurora Line investment (Aurora Line 2).

Other plans to strengthen the main transmission grid
A 400 kV transmission line to be built between Huittinen and Forssa (transmission line 1 in Figure 2) will improve the system security of the main grid and reduce power losses. The new transmission line connection will enable better maintenance and fault outages in the southwest Finland region without degrading the security of the power system. The new transmission line is under construction and is due for completion in 2025.

In the Helsinki metropolitan area, electricity consumption is increasing and electricity production is declining. To ensure the supply of electricity for functions important to society and residents in the region, Fingrid will build a 400 kV cable link from the Länsisalmi substation to the Vanhakaupunki substation in Viikki (transmission line 3 in Figure 2). This project will also reserve space for a second 400 kV cable that could be built in the future. The Helsinki cable will be completed in 2026. In addition, a new 400 kV transmission line will be built from Hausjärvi to the Anttila substation in Porvoo and onwards to the Länsisalmi substation in Vantaa (transmission lines 13 and 14 in Figure 2) in 2030 to cater for the

ever-increasing electricity consumption of the Helsinki metropolitan area. Between Hausjärvi and Anttila, preparations are being made to build the connection with two circuits.

At the Finnish–Swedish border in Tornio, the existing 400 kV Svartby–Keminmaa cross-border connection will be reinforced by replacing the existing lines on the transmission line towers with stronger conductors (transmission line 5 in Figure 2). The project will be completed in 2026.

On the west coast, a 400 kV transmission line is being planned from the Åback substation in Kristinestad to the Melo substation in Nokia (transmission line 8 in Figure 2) to transmit the wind power output from western Finland to consumption centres in the south. The connection will be completed in 2028.

In 2030, a new 400+110 kV transmission line will be built from the Nuojuankangas substation in Vaala to the new Seitenjärvi substation in Ristijärvi (transmission line 12 in Figure 2) to replace the existing 220 kV transmission line, which is reaching the end of its service life. After this, the 220 kV connection from Pyhänselkä to Seitenoikea will be decommissioned from the main grid.

Electricity consumption is expected to increase in the Turku region as a consequence of new electricity-intensive industrial projects. A new 400 kV transmission line from Lieto to Raisio (transmission line 15 in Figure 2) is planned for construction by 2031 to facilitate these projects.

A 400 kV transmission line is planned from the Hikiä substation in Hausjärvi via Siuntio to Ingå (transmission line 16 in Figure 2) to cater for cross-border capacity and increasing electricity consumption. The transmission line is needed before the construction of Estlink 3, the next high-voltage direct current transmission link between Finland and Estonia (transmission line 20 in Figure 2). The Hikiä–Ingå transmission line is planned for commissioning in 2031, and Estlink 3 should be commissioned in 2033.

A new 400 kV transmission line is planned from the new Seitenjärvi substation to be built in the Hyrynsalmi/Ristijärvi area to the new Pontema substation in Utajärvi and onwards to the Pyhänselkä substation in Muhos to enable the increasing wind power output in Kainuu and North Ostrobothnia. In addition, a 400 kV connection will be built between Pontema and Nuojuankangas if it is needed to further increase the transmission capacity (transmission line 19 in Figure 2). Part of the transmission line is expected to be built by a customer and later purchased for integration into the main grid. The transmission line is scheduled for completion in 2032.

A new cross-border line to Sweden, known as Aurora Line 2 (transmission line 2 in Figure 17), is also planned for 2032. Preliminary planning of the transmission line has begun in collaboration with Svenska kraftnät, the transmission system operator in Sweden. Furthermore, the development plan provides for the addition of network compensation solutions, such as synchronous compensators, if required.

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 power system on time. In addition to the transmission line investments, several new substations are planned to cater for wind power. Fingrid is currently analysing the most suitable locations for new transformer substations for this purpose. 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.

A glimpse beyond 2033

The need for further reinforcement of the main transmission grid is expected to continue beyond 2033. Fingrid's network vision, completed in 2023, estimated that the need for electricity transmission within Finland would continue to increase as production 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 transmission lines, series and parallel compensation).

The identified potential solutions that require further investigation are the wider benefits of DLR technology, higher voltages (such as 750 kV), dual 400 kV circuits, and new conductors such as 4-Finch conductors. Shunt compensation and series compensation solutions could speed up their implementation. The potential use of HVDC transmission links within the country could substantially increase the north–south transmission capacity. 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].

The following section covers the 400 kV transmission lines that could be built after 2033. The need for transmission lines will depend on how the structure of electricity production and consumption evolves. Moreover, preparations are being made to strengthen the ageing 400 kV transmission lines by building new or replacement connections.

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

Around the mid-2030s, the main grid's transmission needs are highly likely to require strengthening of the existing 400 kV connections with two-part conductor elements. These connections are the 400 kV River Lines (transmission line A in Figure 3) and the Seinäjoki–Alajärvi–Ulvila connection on the west coast (transmission line B in Figure 3). The connections will be strengthened either by replacing the existing transmission lines or building new transmission lines alongside them with three conductor elements. The routes and exact termini of the new transmission lines are not yet known.

There are several large-scale electricity production projects and electricity-intensive industrial projects on the west coast. If these projects are implemented on a large scale, further new 400 kV transmission lines will need to be built from the west coast to the south (area C in Figure 3). The exact routes and termini of the new transmission lines will depend on the locations and progress of customer projects. At present, the most likely transmission line connections are a connection from Kankaanpää to the Helsinki metropolitan area (transmission line D in Figure 3) and a connection from Rauma to Ingå via the Lieto substation (transmission line E in Figure 3). Estlink 3, a new high-voltage direct current cable to Estonia, is being planned from Ingå.

Several wind and solar power projects are planned in Kainuu and North Ostrobothnia. If they come to fruition, new 400 kV transmission line connections will be needed. A 400 kV transmission line is planned from the Pontema substation, to be built to the west of Puolanka, to the Pudasjärvi area in the north (transmission line F in Figure 3). From there, the transmission line will continue to the new Herva substation in Ii (transmission line G in Figure 3) and the Pirttikoski substation in Lapland (transmission line H in Figure 3). The transmission line

between Herva and Pudasjärvi may be built partly by a customer and later purchased for integration into the main grid. The new transmission lines will enable the connection of new production projects to the grid and the development of the distribution network in the region.

Lapland's existing 220 kV network may run low on transmission capacity if wind power projects are realised on a large scale in Lapland. A 400 kV transmission line is planned alongside the 220 kV meshed grid to increase the transmission capacity and connect major production projects (transmission line I in Figure 3). New 400 kV transmission lines are likely to be built from the Pirttikoski substation to the Petäjäskoski substation via the Isoniemi and Vajukoski substations. A 400 kV mesh will be built in phases as projects in the region progress. The first section may be built between the Pirttikoski and Kellarijänkä substations.

The main grid in Eastern Finland currently consists of long 110 kV ring connections. The transmission capacity and voltage stability of the 110 kV network is insufficient for the connection of the large-scale electricity production and consumption projects planned in Eastern Finland. New 400 kV transmission lines are planned in Eastern Finland to facilitate these projects by boosting the transmission capacity (area J in Figure 3). The construction of the transmission lines depends on the progress of customer projects in order to determine the termination points of any necessary transmission lines. Among the factors significantly affecting the progress of projects are the Finnish Defence Forces' air surveillance policies. At present, one of the most likely 400 kV transmission lines is a connection from the Huutokoski substation to the Kontiolahti substation (transmission line K in Figure 3).

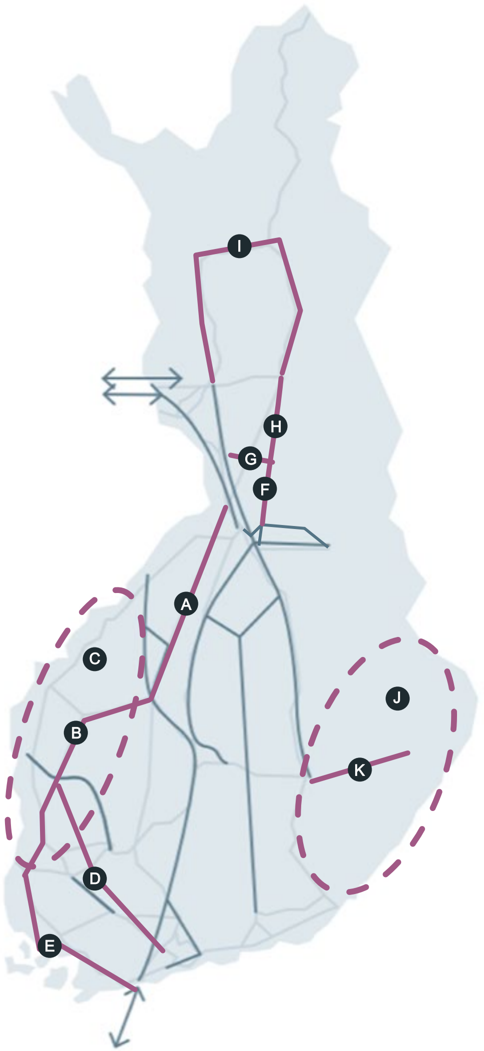


Figure 3. Potential development needs in the main transmission grid after 2033.

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 and Estonia 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. The high-voltage direct current transmission link to Russia was decommissioned in 2022 as a consequence of the economic sanctions imposed on Russia for invading Ukraine. In early 2023, the commercial transmission capacities of connections managed by Fingrid and made available to the electricity markets were as follows (From Finland / To Finland).

Sweden:	2,300 / 2,400 MW
Estonia:	1,016 / 1,016 MW

The transmission capacities of AC connections are traditionally defined under the Net Transfer Capacity (NTC) principle, which refers to the maximum commercial import capacity. Consequently, they have remained fairly stable, as changes only arise during outages for maintenance and faults. The Nordic transmission system operators are currently executing a project to transition to the Flow-Based Method of determining commercial transmission capacities between electricity market areas. This method is expected to make capacity available to the market more efficiently, taking into account various transmission situations. The transition to the Flow-Based Method is currently expected to take place in 2024. Preliminary estimates indicate that the change will not significantly affect the market capacities of Finland's cross-border connections in comparison with the current NTC method.

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	Keminmaa–Petäjäskoski 400 kV connection 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
16	Forest Line	2022

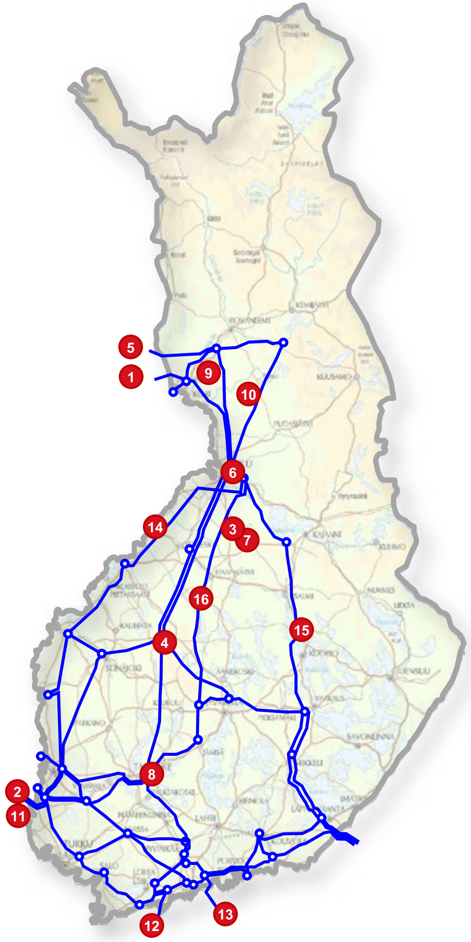


Figure 4. Investments in cross-border lines and the year in which they were commissioned

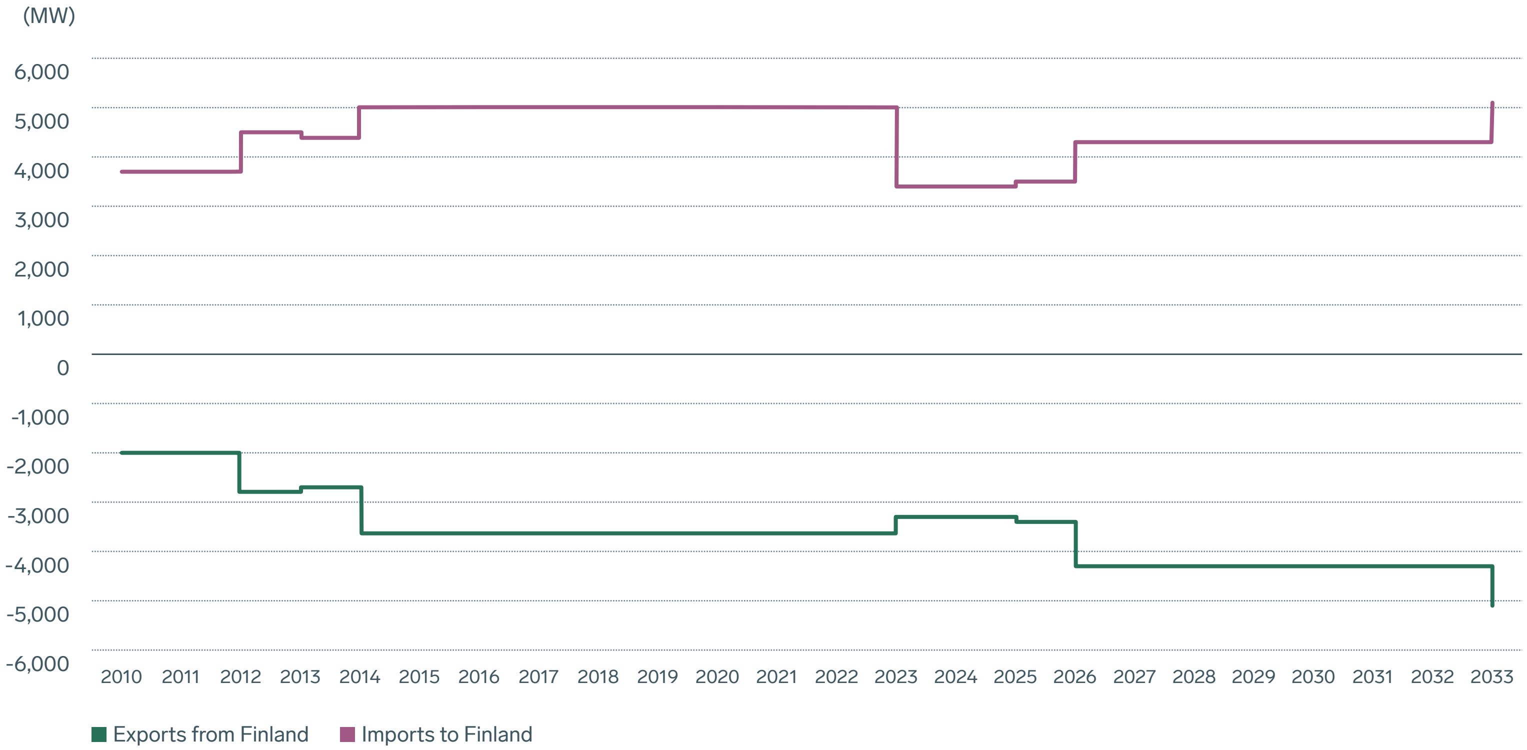


Figure 5. Development of cross-border capacity 2010–2023 and planned development 2024–2033.

Sweden

In early 2023, the alternating current capacity between northern Finland and northern Sweden was 1,200 MW of imports from Sweden to Finland and 1,100 MW of exports from Finland to Sweden. If the production output of the Olkiluoto 3 nuclear power plant unit falls below 1,000 MW, the available import capacity on the AC connections from Sweden to Finland can be raised by 300 MW to 1,500 MW. In addition to the AC connections in the north, the cross-border capacity between Finland and Sweden is supplemented 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 in autumn 2016 to move forward with the implementation of the Aurora Line, which will be the third alternating current connection between the countries. Construction began in 2022.

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

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 awarded the project EUR 127 million in funding due to the Aurora Line's significance. The funding was granted under the Connecting Europe Facility. 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 total transmission capacity between the countries. A transmission line will be built from Messaure in Sweden to the Viitajärvi substation in Finland and onwards to the Pyhänselkä substation. The transmission line will be approximately 400 kilometres long. The project is estimated to cost EUR 250 million. The common goal of Fingrid and Svenska kraftnät is to commission the transmission line connection by the end of 2025.

The results of Fingrid's network vision, published in 2023, indicate that raising the cross-border transmission capacity will still be beneficial by 2035. In late 2022, Fingrid and Svenska kraftnät initiated a study to gain more insight into the implementation of the next cross-border line. PCI status has also been sought for the next cross-border line, known as Aurora Line 2. Fingrid's development plan foresees the commissioning of Aurora Line 2 in 2032.

Co-funded under the European Union
Connecting Europe Facility

Figure 6. The route of Aurora Line 1 in Finland and Sweden.

Estonia

There are two HVDC transmission links between Finland and Estonia: EstLink 1 (350 MW) and EstLink 2 (650 MW). In its system 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 Poland in the future. Fingrid and Elering are currently initiating a study to gain greater insight into the profitability and timing of the EstLink 3 connection. Planning will also continue as part of international grid planning cooperation by applying for PCI status for EstLink 3, among other things. Fingrid's development plan foresees the commissioning of EstLink 3 in 2033.

Norway

Fingrid and Statnett, the Norwegian transmission system operator, have examined the development of transmission connections between northern Finland and northern Norway. The possible need for transmission capacity is associated with the increase in electricity consumption by industries in northern Norway and the possibility of exploiting the wind power potential in the region. The problem in northern Norway is that the Finnmark region is poorly connected to 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 (with a capacity of approximately 100–150 MW) into an HVDC transmission link with a corresponding transmission capacity by constructing a back-to-back HVDC substation on Norway's side of the border. Statnett's preliminary timetable for the project is around 2030. 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. Alongside the modernisation of the cross-border connection, Statnett intends to strengthen its own grid in northern Norway in phases towards the Finnish border.

Investment plan by region

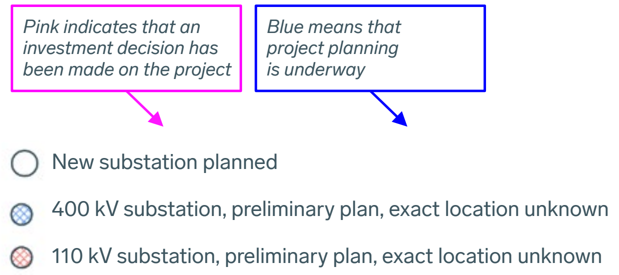
The following sections describe the development plans for the main grid in various parts of Finland. There are four planning areas: Northern Finland, Eastern Finland, Western Finland and Southern Finland. Each region is divided into 2–4 smaller areas to make the review easier to follow. The areas were selected according to geographical and electrotechnical criteria.

The sections examine the characteristics of the planning areas, main grid investments in recent years, and current development plans. The planned projects are shown on maps where 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. The transmission lines owned by other companies are shown in black. The investments are also marked with symbols as shown in Figure 7.

The information and timetables of the planned investments are preliminary and will become more specific as the date of implementation draws closer. The final method of implementation and the timetable will be clarified when an investment decision is made. This enables Fingrid to react rapidly to requirements arising from changes in the operating environment. In particular, the numerous wind and solar power projects, hydrogen and industrial projects, and the related uncertainties could alter the grid development needs rapidly. Various tools are used to improve the monitoring of customer projects, including reports and dynamic maps, which are used to support planning. These also enable proactive and flexible decision-making.

The development plan is updated every two years so that the work provides a snapshot of the projects included in Fingrid's investment plan over the next 10 years. As a whole, the investment plan is updated as part of a continuous process in accordance with the changing needs of the operating environment.

Markings on the regional investment plans:



* The investment schedule depends on the schedules of the customers' projects

Figure 7. Markings on the regional investment plans.

The following factors will affect the main grid investment plan and the related timetables:

- The needs of Fingrid's existing and future customers
- Changes in the electricity market in Finland and its neighbouring countries
- Changes in the energy policy in Finland and 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
- Land use and environmental requirements and permit application procedures

As a result of route planning and the related environmental studies or environmental impact assessments (EIA), the line routes presented in the main grid development plan will be revised as planning progresses if the projects have not yet progressed to these phases. The factors affecting the locations of substations include the positions of transmission line junctions, soil and outcomes of nature surveys. Based on the clarified route plans and substation location plans, Fingrid will prepare for the new land use needs as required by the electricity transmission grid.

Northern Finland

Description of the region

The northern Finland planning area covers more than a third of Finland's total territory. Most of the region is sparsely populated, and the transmission distances are long. The 400 kV network extends from the Pyhänselkä and Pikkarala substations at the Oulujoki latitude to the Petäjäskoski and Pirttikoski substations at the Rovaniemi latitude. From there, the main grid extends north on 220 kV lines. The 220 kV voltage level is better suited to long transmission distances than a 110 kV grid, but it is less robust and has a lower transmission capacity than a 400 kV grid. When faults arise in the 220 kV grid area in Lapland, one distinct characteristic is power fluctuations, which often call for the use of stabilisation devices to dampen fluctuations, even at converter-connected power plants. The region has 400 kV transmission links to Sweden via Tornio and Ylitornio, and the Aurora Line, a third 400 kV AC connection between Finland a Sweden, is under construction. There is a 220 kV cross-border line between Norway and Finland at Utsjoki.

The largest electricity consumers in the region are the steel and forest industries, mines, ski resorts and the largest urban areas, such as Oulu and Rovaniemi. The Outokumpu steelworks in Tornio is the largest individual electricity consumer in the Nordic countries. Metsä-Fibre is replacing its Kemi pulp mill with a bioproduct factory, which will be the largest factory investment in the history of the Finnish forestry industry. The Elijärvi mine in the Lapland region is the only chromite ore mine in the EU, and the Suurkuusikko gold mine is the largest in Europe. The Kevitsa mine is one of the largest employers in Finland's mining industry.

Electricity production in the region consists mainly of hydro and wind power, as well as power plants at industrial plants. The coastal area between Kemi and Oulu contains a large concentration of wind power, and the planning area also covers a significant number of new wind power projects in the planning phase. The planning area encompasses hydro power plants on the Rivers Kemijoki, Iijoki, Kitinen and part of Oulujoki, constituting the majority of Finland's hydro power production. During flooding season, typically in May, the hydro power plants produce electricity at full power. At other times, hydropower can be adjusted according to the market situation.

Recent investments in the northern Finland grid

Substantial investments have been made in the northern Finland grid in the 2010s and 2020s. The 220 kV Petäjäskoski–Valajaskoski–Isoniemi–Vajukoski ring connection was completed at the start of the 2010s, and a new 220 kV substation was built in Kuolajärvi on the Isoniemi–Vajukoski section to connect wind power. The Pirttikoski, Petäjäskoski and Vajukoski substations were also upgraded with the addition of second main transformers, and system security was improved.

Wind power production capacity has already been constructed in Sea Lapland, with plenty more expected in the coming years. The main grid was reinforced in the mid-2010s 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 transmission line connections between the Isohaara and Keminmaa substations and the Taivalkoski and Keminmaa substations. Furthermore, the conductors in the 110 kV Isohaara–Raasakka transmission line between Kemi and Iijoki have been replaced with conductors that have 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.

In recent years, the Taivalkoski, Ossauskoski, Keminmaa, Pikkarala and Meltaus substations were refurbished, and a quenching choke was added to the Meltaus substation. In addition, the Raasakka substation was modernised. An extension of the Isoniemi substation was completed in 2021 to improve system security, and a second main transformer was added to the substation. The new Simojoki 110 kV substation was completed in Simo in 2021 to connect wind power to the grid and alleviate the outages in the area. The new Kellarijänkä 220/110 kV substation was completed in Kemijärvi in 2023 to connect wind power to the grid and enable the development of the region's distribution network.

Development plan for northern Finland

Investments in the northern Finland grid have improved the opportunities to connect new production and consumption to the grid. However, the ever-increasing number of wind power projects, growing turbine sizes, industrial projects and increasing cross-border capacity call for even larger investments in grid development.

Investments in the northern Finland grid have improved the opportunities to connect new production and consumption to the grid.

Development plan for the Lapland region

Transmission line projects

The transmission lines in the Lapland planning area are mainly in good condition. The sharp increase in wind power production in the Lapland region will likely require new 400 kV transmission lines (see "A glimpse beyond 2033"). Aurora Line 2, a new 400 kV cross-border line, is planned for completion in 2032. Preliminary studies are underway with Svenska kraftnät, the Swedish transmission system operator. The transmission line's termini and route are not yet known. In the Rovaniemi and Sodankylä areas, an existing section of the 110 kV transmission line between the Meltaus substation and the Lintuselkä disconnector substation will be modernised, as appropriate for its condition, by 2030.

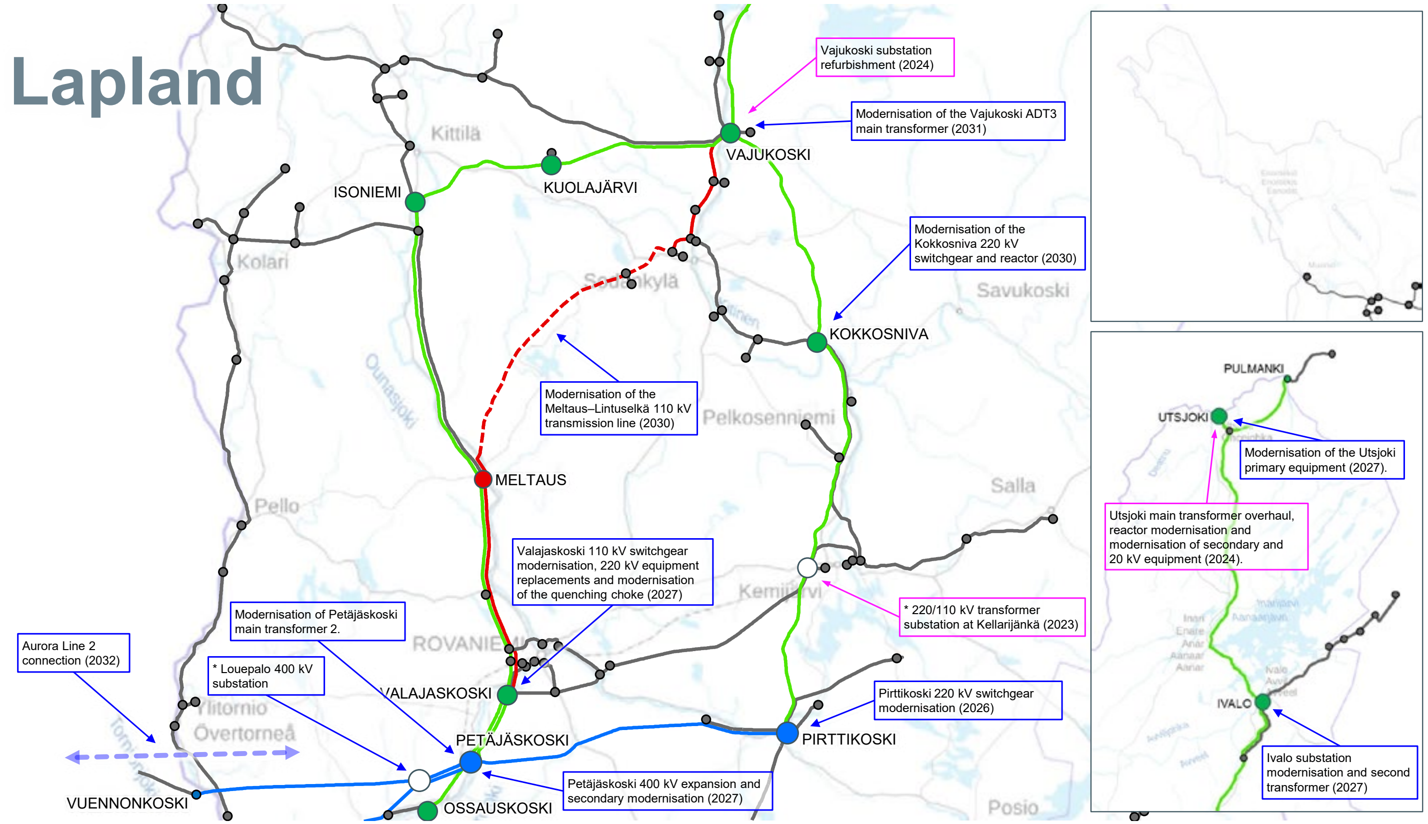


Figure 8. Development plan for the Lapland region.

Substation projects

Most of the substation projects in the Lapland region are expansions of and modernisations of existing substations, according to their condition. Projects scheduled for completion from 2024 to 2026: An overhaul of the Utsjoki main transformer, a reactor modernisation and the replace of the secondary system and 20 kV equipment will be completed in 2024. The Vajukoski substation refurbishment project will also be completed in 2024. The Pirttikoski 220 kV switchgear will be modernised in 2026, as appropriate for its condition.

Several projects will be completed in 2027: The Ivalo substation will be modernised, and a second main transformer will be added to the station as a backup to the existing main transformer. The Valajaskoski 110 kV switchgear, some of the 220 kV installations and the quenching choke will be modernised, as appropriate for their condition, and the primary substation equipment in Utsjoki will be modernised. The Petäjäskoski 400 kV switchgear will be expanded to accommodate the new 400 kV Petäjäskoski—Nuojuankangas transmission line.

In 2030, the ageing main transformer at Petäjäskoski, consisting of single-phase units, will be modernised, and the 220 kV switchgear and reactors in Kokkosniva will be modernised. In addition, the Ossauskoski substation will be refurbished. If necessary, the transformer capacity at the Pirttikoski substation will be increased as wind power projects progress. A new substation is planned for Louepalo, west of Petäjäskoski, also to connect wind power production. The implementation schedule for the new substation will depend on the progress of wind power projects.

The fire service contract principle in the Lapland region was discontinued in 2021. Fingrid is now solely responsible for maintaining fire extinguishing capacity. Quenching chokes were added to the Meltaus and Kellarijänkä substations, and the quenching choke at the Valajaskoski substation will be modernised in 2027.

Development plan for the Sea Lapland region

Transmission line projects

A new cross-border line known as the Aurora Line is under construction between Finland and Sweden to increase the electricity transmission capacity between the countries. In Finland, the Aurora Line will travel from the Pyhänselkä substation in Muhos via the Simojoki substation to the Viitajärvi substation in Keminmaa and onwards to the border via Ylitornio. A transmission line series compensation station will be built in Yli-Ii in Oulu. The new Herva substation in Ii is also planned along the transmission line to serve as a collecting station for wind power. The Aurora Line will be completed at the end of 2025. Fingrid is already planning the next cross-border line, known as Aurora Line 2, with Svenska kraftnät, the Swedish transmission system operator, with the aim of completing the line in 2032. The route and termini of Aurora Line 2 are not yet known.

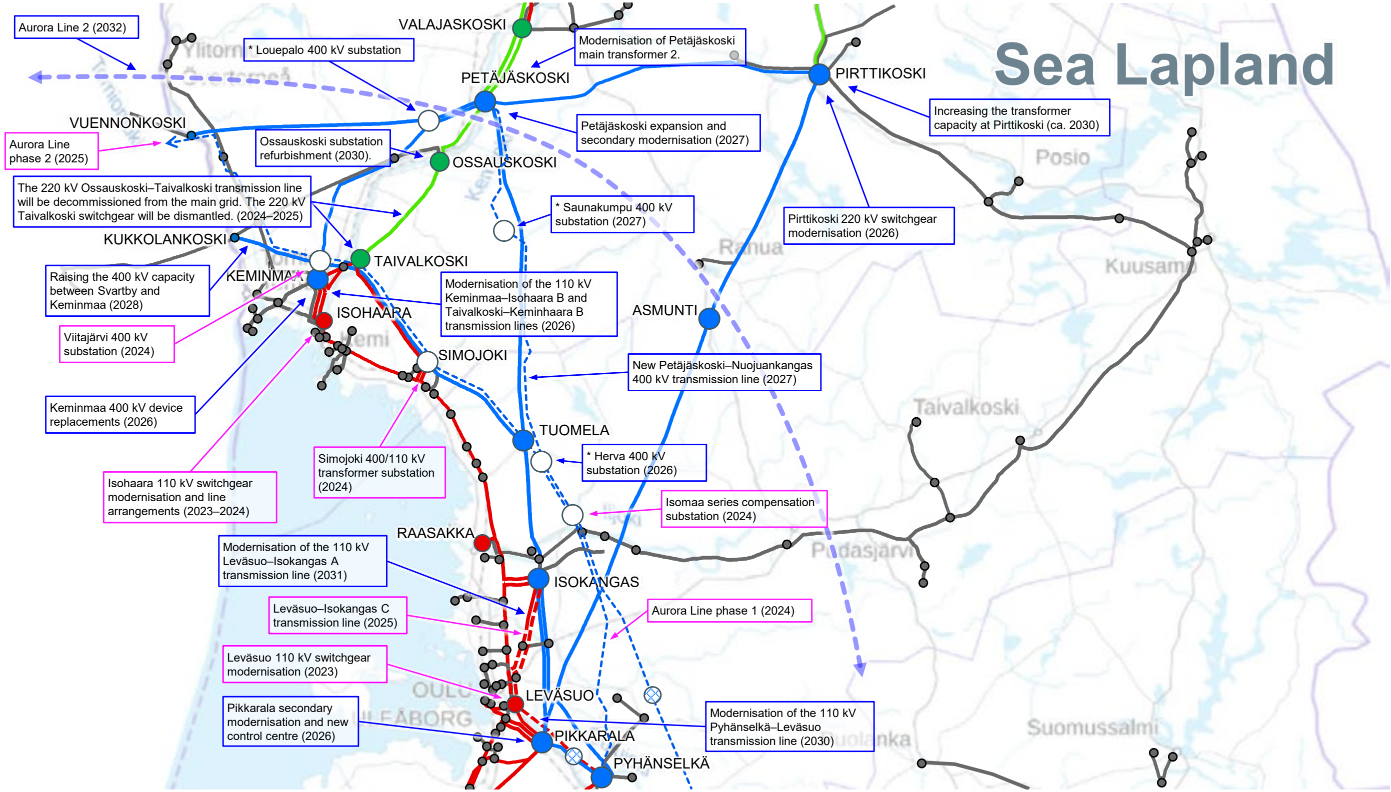


Figure 9. Development plan for the Sea Lapland region.

In addition to the cross-border line investments, the wind power projects north of Cross-section Kemi–Oulujoki require investments to strengthen the grid from north to south. A 400 kV connection from the new Nuojuankangas substation in Vaala to the Petäjäskoski substation is planned. The planned transmission line can be completed after the duplication of the Lake Line in 2027. The new Saunakumpu 400 kV substation in Simo is planned along the transmission line to connect wind power. The new Petäjäskoski–Nuojuankangas transmission line will travel via the new Herva substation on the Aurora Line.

In 2025, a third 110 kV transmission line will be completed to the north of Oulu from the Leväsuo substation to the Isokangas substation. This transmission line will increase the transmission capacity of the 110 kV grid north of Oulu as the production surplus increases in the area between Oulu and Keminmaa. At the same time, the existing and ageing Leväsuo–Isokangas A transmission line will be modernised. The remainder of the A connection will be modernised as appropriate for its condition in 2031. The Isohaara substation was modernised in 2023. In connection with this, the ageing 110 kV transmission lines to the north and south of the substation will be modernised. The transmission line works will be completed in 2024.

The 220 kV voltage level will no longer be used at the Taivalkoski substation after 2024 when the Simojoki 400/110 kV transformer substation and the 400 kV Pyhänselkä–Viitajärvi section of the Aurora Line are completed. The 220 kV transmission line between Taivalkoski and Ossauskoski will also be decommissioned from the main grid. Taivalkoski will retain 110 kV connections to the Simojoki and Keminmaa substations. The 220 kV voltage level will be discontinued due to the ageing of the Ossauskoski–Taivalkoski transmission line and the Taivalkoski transformers.

Substation projects
As regards substation projects, several projects are underway or upcoming, including refurbishments of existing substations, some substation expansions, and a few new substations to connect new wind and solar power production to the grid.

Projects scheduled for completion in 2024: The new Viitajärvi 400 kV substation will be built in Tornio for the Aurora Line. The ongoing conversion of the Simojoki 110 kV substation into a 400/110 kV substation will be completed in the same year.

Projects scheduled for completion in 2025 and 2026: The Isokangas 110 kV switchgear will be expanded for the third Isokangas–Leväsuo transmission line in 2025. As wind power projects progress, the Herva 400 kV substation will be built to the south of the existing Tuomela series compensation station in Ii in 2026. The timetable for the Herva substation could still change depending on the progress of wind power projects.

In 2027, the Petäjäskoski 400 kV switchgear will be expanded to accommodate the new 400 kV Petäjäskoski–Nuojuankangas transmission line, and the 400 kV secondary system at the substation will be modernised. In addition, the new Saunakumpu 400 kV substation will be built in the municipality of Simo to connect wind power to the Petäjäskoski–Nuojuankangas transmission line. The timetable for the Saunakumpu substation may change according to the progress of wind power projects.

Projects scheduled for completion from 2030 to 2033: In 2030, the ageing main transformer in Petäjäskoski, consisting of single-phase units, will be modernised, and the related 400 kV line arrangements will be made. The Ossauskoski substation will be refurbished in the same year. The new Louepalo 400 kV substation is planned to the west of Petäjäskoski to connect new wind power production to the grid. Two other 400 kV substations are also planned to connect wind and solar power to the grid. One of these will be in the area between the Pirttikoski and Pyhänselkä substations, and the other will be on the Petäjäskoski–Nuojuankangas transmission line at the Oulu latitude. The timetables of the new substations depend on the progress of customer projects.

Eastern Finland

Description of the region

The Eastern Finland planning area consists of the regions of Kainuu, Savo-Karelia and Southeast Finland. These regions cover about one-third of Finland's territory. One of the five 400 kV transmission lines on the north–south axis runs through the planning area from Kainuu via Savo-Karelia to Southeast Finland. The 110 kV meshed grids in Kainuu and Savo-Karelia are characterised by long transmission line distances. The 110 kV electricity transmission grid in Kainuu connects to the 400 kV and 220 kV main transmission grid via the Vuolijoki and Seitenoikea transformer substations. The 110 kV grid in Savo-Karelia is supplied by the Alapitkä, Huutokoski and Visulahti 400/110 kV transformer substations. The 110 kV grid in the Southeast Finland area is connected to the 400 kV grid via the Koria, Kymi and Yllikkälä 400/110 kV transformer substations.

Electricity consumption in the Eastern Finland planning area is mainly concentrated in the largest urban areas, such as Kajaani, Kuopio, Joensuu, Mikkeli, Lappeenranta, Kouvola and Kotka. Electricity consumption in the Kainuu and Savo-Karelia areas primarily consists of consumption by services and households. In the future, when heat is increasingly produced using electricity, combustion-based production will decline to be replaced by solutions such as electric boilers. The change will raise the electricity deficit significantly in urban areas. In addition, the Eastern Finland area is also home to a few industrial facilities and mines with significant transmission volumes in the main grid. The Southeast Finland region traditionally contains a lot of energy-intensive forest industry and some metal, mining, and chemical industry production facilities. A few industrial projects that are significant for the main grid are planned in Eastern Finland, especially in the Southeast Finland region.

Electricity production in the Eastern Finland planning area consists mainly of hydro and wind power in Kainuu. Tens of thousands of megawatts of new wind power production is planned in the eastern parts of Kainuu and North Ostrobothnia, and the current output is approximately 600 MW. Electricity production in Savo-Karelia consists of heating plants in towns and cities, industrial CHP plants, and dispersed hydro power plants. Hydro power is dispersed around the Southeast Finland region in small units, with the exception of Finland's largest hydropower plant in Imatra, which outputs nearly 200 MW. 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 Loviisa nuclear power plant is on the border of the Southeast Finland planning area.

Recent investments in the Eastern Finland grid

In recent years, investments have been made to boost the system security and transmission capacity in the region. The ageing network has also been modernised.

The old Tihisenniemi substation in Kainuu was converted to gas-insulated switchgear in 2019. The ageing 220 kV network in the area was modernised with the construction of a new 400/110 kV transformer and 110 kV switchgear at Pyhänselkä in 2021. The 220 kV Utanen and Nuojua substations were modernised to become 110 kV switchgear alongside the existing substations in 2022. The new substation built to replace the Nuojua substation was named Nuojuankangas. At the same time, a 400+110 kV connection was built between Pyhänselkä and Nuojuankangas. The connection is initially operated at 110 kV, but 400+110 kV operation will begin once the

Lake Line duplication is completed in 2026. A reactor was added to Seitenoikea in 2022 to help with voltage control in the remaining 220 kV grid.

The fifth 400 kV north–south connection from Petäjävesi to Pyhänselkä, known as the Forest Line, was completed in 2022, and the 220 kV network from Petäjävesi to Haapajärvi was decommissioned from the main grid. At the same time, the 220 kV transmission line from Pysäysperä to Nuojuankangas was commissioned for operation at 110 kV. When the Forest Line was completed, the Pyhäkoski substation was dismantled, except for the 220 kV switchgear, and its operations were taken over by the adjacent Pyhänselkä substation.

In the Savo-Karelia region, the Huutokoski 110 kV switchgear was modernised and converted to gas-insulated switchgear in 2018. A new 110 kV gas-insulated switchgear was completed in the same year in Iisalmi, replacing a customer's Peltomäki switchyard as a main grid hub. A refurbishment project was completed at the Alapitkä substation 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 voltages in the north Karelia area. The project to refurbish and expand the Kontiolahti substation was completed in 2020. Among other additions, the substation gained a second main busbar.

The Kontiolahti–Uimaharju–Pamilo project package was completed in 2022. The package included the modernisation of the 110 kV Kontiolahti–Uimaharju, Uimaharju–Pamilo, and Pamilo–Kaltimo–Kontiolahti transmission lines between the substations. In conjunction with this modernisation, the new Palojärvi substation replaced the Pamilo substation. When the project package was completed, the 110 kV Kiikanlahti–Pamilo transmission line was brought into Kontiolahti, creating a new 110 kV Kontiolahti–Kiikanlahti transmission line connection. The old final section was in poor condition and was demolished.

The Koria substation project was carried out in Southeast Finland in 2019, including the refurbishment of the 110 kV switchgear, modernisation of the 400 kV switchgear, and addition of a reactor to the substation. The new 110 kV substation in Vuoksi was commissioned in 2018, and the section of the 110 kV transmission line from Imatra to Lempiälä was modernised to boost transmission capacity in 2019.

The new 110 kV Tehtaanmäki substation was built in Anjalankoski in 2020 to replace ageing independent circuit-breakers. In addition, the 110 kV Pernoonkoski substation was refurbished in 2020, and the 110 kV Imatra substation was modernised. The 110 kV Imatra–Huutokoski transmission line, which was built in the 1930s, was modernised in 2022. In the same year, a reactor was added to the Yllikkälä substation when it was refurbished. In 2023, the Luukkala 110 kV substation will be converted into an SF6-free gas-insulated switchgear plant.

Development plan for the Kainuu region

Previous investments in the Kainuu region have created a network with sufficient transmission capacity and system security for the needs of services, households and industry in the region. Today, tens of thousands of megawatts of wind power are planned in the region, so the main grid requires substantial reinforcement.

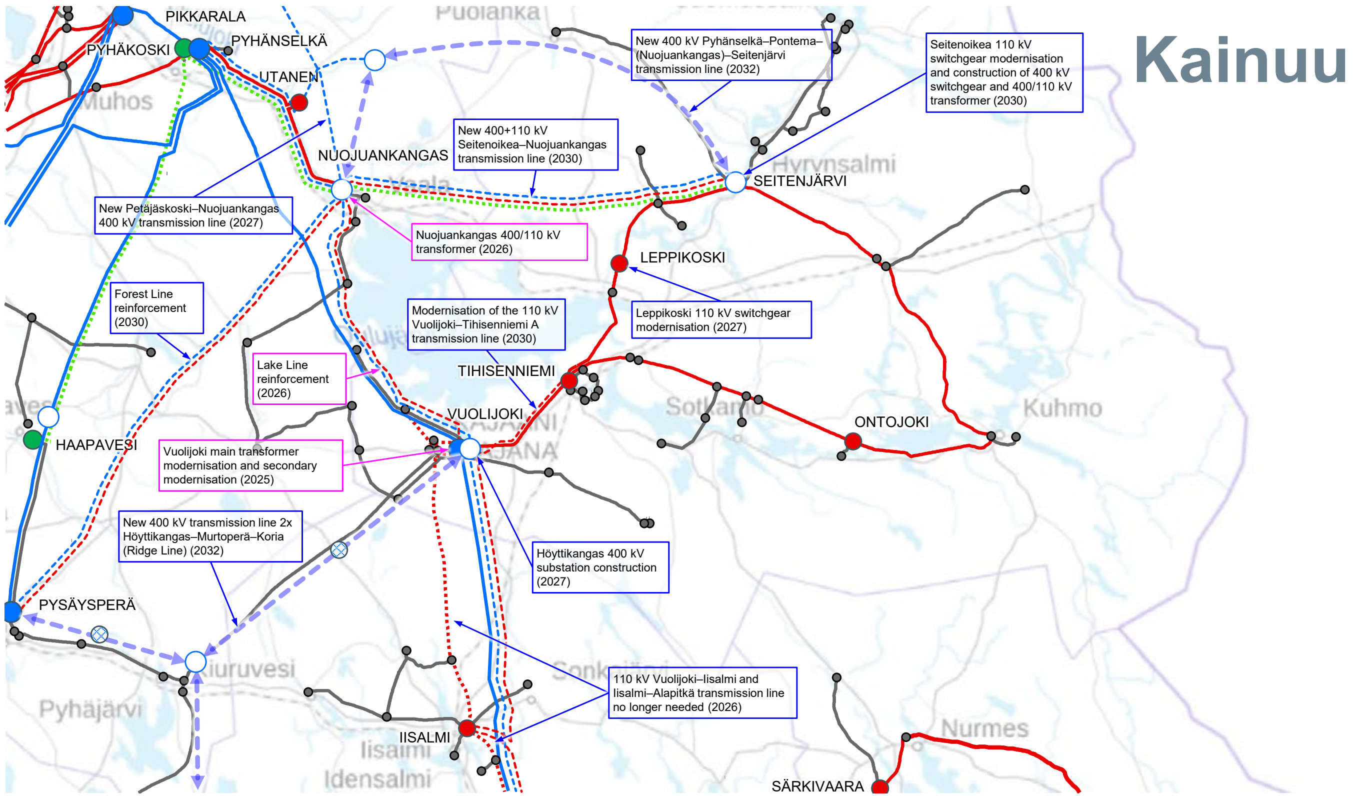


Figure 10. Development plan for the Kainuu region.

Transmission line projects

In late 2022, the decision was taken to invest in the strengthening of the Lake Line with the construction of a 400+110 kV transmission line from Nuojuankangas to Huutokoski, due for completion in 2026. The new line will increase Finland's north–south transmission capacity and enable wind power in the Kainuu region to be connected to the grid. At the same time, the existing 400+110 kV Pyhänselkä–Nuojuankangas transmission line will be converted from 110 kV operation to 400+110 kV operation. After the Lake Line is reinforced, a new 400 kV connection between the Petäjäskoski and Nuojuankangas substations will be completed in 2027.

A large number of wind power projects are in the planning stage in the Kainuu and North Ostrobothnia regions. The large-scale connection of wind power will require 400 kV network solutions, and these are currently in the planning stage. In the first phase, the plan is to replace the 220 kV Nuojuankangas–Seitenoikea transmission line with a new 400+110 kV Nuojuankangas–Seitenjärvi connection in 2030. An environmental impact assessment for the project is currently underway. In the next phase, in 2032, the plan is to strengthen the 400 kV network in Kainuu from Pyhänselkä via the new Pontema substation to Seitenjärvi and Nuojuankangas. In 2030, the ageing Vuolijoki–Tihisenniemi A 110 kV transmission line will be modernised.

The Forest Line will need to be reinforced in 2030 to increase the north–south transmission capacity from the Nuojuankangas substation via Pysäysperä to Central Finland. As the volume of wind power continues to increase, the need for north–south transmission capacity will probably call for the construction of the new 400 kV Ridge Line from the new Höyttikangas substation and the Pysäysperä substation via Pyhäjärvi to Southern Finland. The Ridge Line is expected to be completed in 2032.

Substation projects

When the Lake Line is reinforced, the main transformers in Vuolijoki will be modernised in 2025. In 2026, the Nuojuankangas substation will be expanded with the addition of 400 kV switchgear and a 400/110 kV transformer. The new Höyttikangas substation is planned for construction near the Vuolijoki substation to connect wind power to the grid. The substation project will be executed as wind power projects in the region progress. The 110 kV Leppikoski switchgear will be modernised in 2027.

A large number of wind power projects are in the planning stage in the Kainuu and North Ostrobothnia regions.

Development plan for the Savo-Karelia region

There is currently no need to carry out significant reinforcements to increase the 110 kV grid transmission capacity in the Savo-Karelia area. Investments over the next ten years will mainly be due to the ageing grid. However, it should be noted that new development needs in the region may arise at short notice as new industrial or electricity production projects progress.

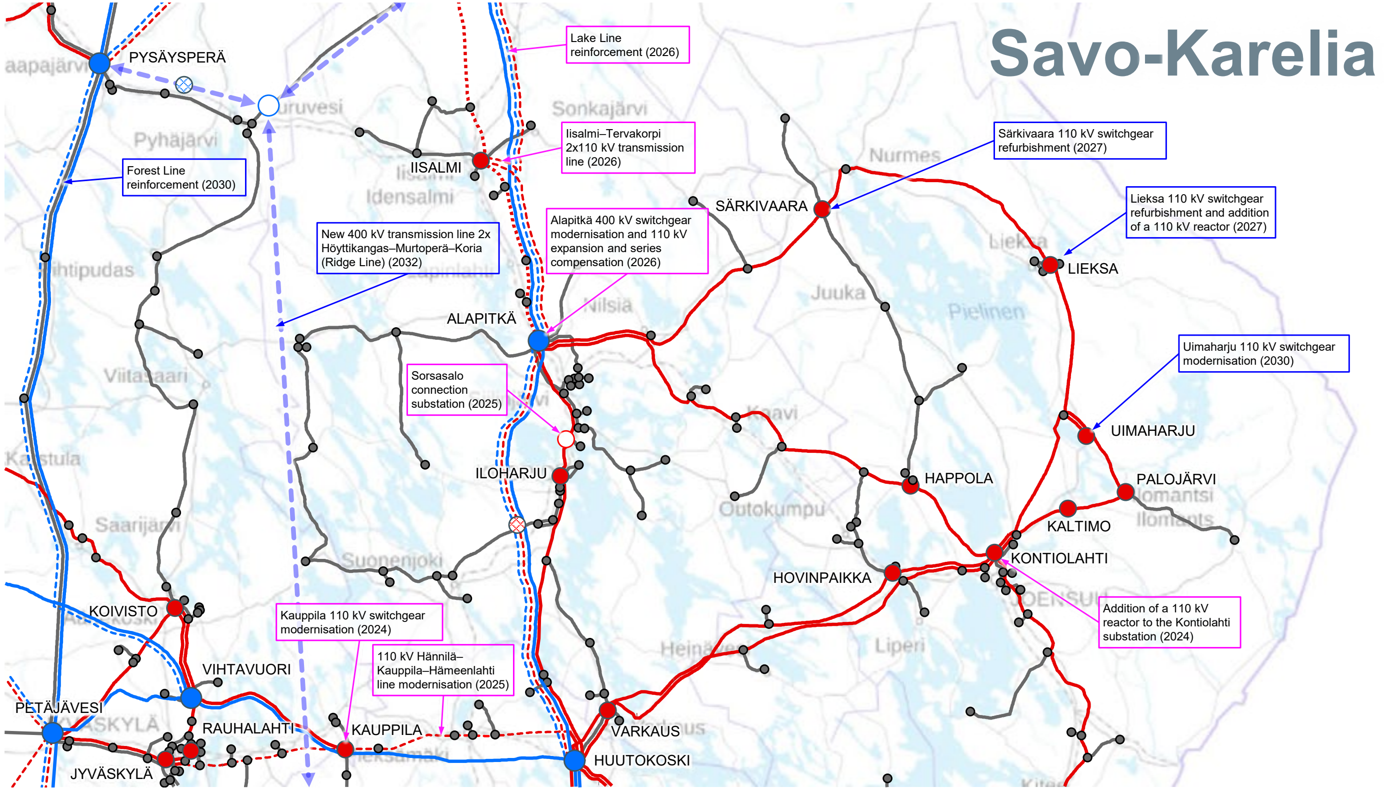


Figure 11. Development plan for the Savo-Karelia region.

Transmission line projects

The modernisation of the ageing 110 kV Huutokoski–Kauppila–Hämeenlahti transmission line, due for completion in 2025, will increase the transmission capacity and enable wind power to be connected to the grid in the Pieksämäki area. The Lake Line, which passes through the planning area, will be reinforced in 2026: a new 400+110 kV transmission line from the Nuojuankangas substation to Huutokoski will increase the north–south transmission capacity and further improve the capacity to connect renewable electricity production. The 400 kV Ridge Line, running from the Höyttikangas and Pysäysperä substations via Pyhäjärvi to Southern Finland, will also be completed in 2032.

Substation projects

In spring 2021, the decision was made to invest in a reactor to be installed in Kontiolahti in 2024 to ease the occasional voltage problems in the area. The modernisation of the 110 kV Huutokoski–Kauppila–Hämeenlahti transmission line will increase the transmission capacity and enable wind power to be connected to the grid. In connection with the modernisation, the 110 kV Kauppila substation will be converted to a gas-insulated switchgear station in 2024. When the Lieksa and Särkivaara substations are refurbished in 2027, a second reactor will be added to Lieksa to facilitate voltage management in north Karelia. The new 110 kV Sorsasalo connection substation will be built along the Iloharju–Alapitkä transmission line in 2025. In the same year, the ageing 110 kV Savonlinna substation will also be modernised. A new substation, to be named Olavinlinna, will be built alongside the existing one. When the Lake Line is reinforced in 2026, the 400 kV Alapitkä switchgear will be modernised.

Southeast Finland

Development plan for the Southeast Finland region

Thanks to investments already completed, Southeast Finland has sufficient grid capacity and system security. Some major consumption projects are currently being planned for the area, and these may require new investments in the main grid. The necessary investments will be clarified as projects progress to implementation.

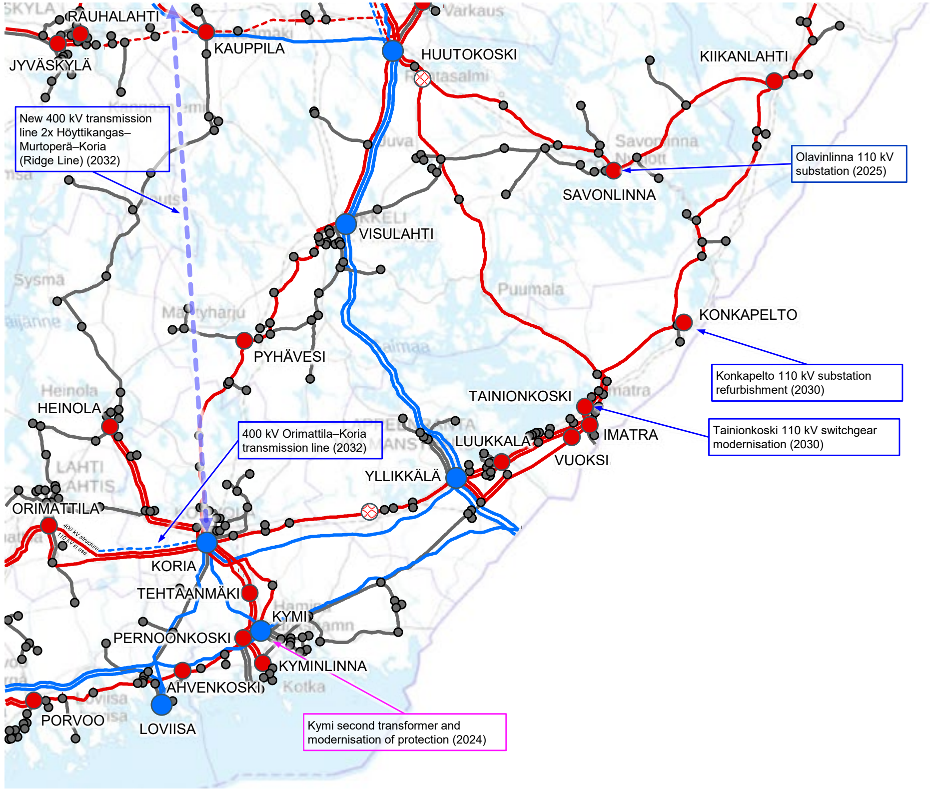


Figure 12. Development plan for the Southeast Finland region.

Transmission line projects

The new 400 kV Ridge Line, running from the Höyttikangas and Pysäysperä substations via Pyhäjärvi to Southern Finland, is expected to be completed in 2032. In the long-term, there is a need to make provisions for a 400 kV connection between the Orimattila and Koria substations as east–west transmission needs increase.

Substation projects

As a consequence of increased consumption in the region, a second main transformer will be added to the Kymi substation in 2024. At the same time, the secondary equipment at the substation will be modernised. In 2030, the 110 kV Tainionkoski substation will be modernised as appropriate for its condition, and the 110 kV Konkapelto substation will be refurbished.

Western Finland

Description of the region

The western Finland planning area borders Oulu, Jyväskylä, Tampere and Pori. Approximately one million people live in the area.

The largest industrial clusters in the region are SSAB's steelworks in Raahe, the Kaskinen chemi-thermomechanical pulp plant, the Jakobstad paper and pulp mills, the Kokkola zinc plant, greenhouse cultivation in Närpes and its surrounding areas, and the large forest industry clusters in the Jämsä river valley, Äänekoski and Mänttä.

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. In addition, the Rauhalahti and Keljonlahti power plants in Jyväskylä generate electricity and district heating. There are also a few smaller hydro power plants in the area. Most of the wind power planned for construction in Finland is located on the Ostrobothnian coast. At present, approximately 4,200 MW of wind power is in operation in the planning area, and 1,900 MW more is under construction.

Recent investments in the western Finland grid

The main grid in Ostrobothnia 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 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 Coastal Line has proven an important main grid connection with the significant increase in wind power production in Ostrobothnia.

Fingrid has built several substations along the Coastal Line to connect wind power to the grid. A new 110 kV substation was completed in Siikajoki in 2016 and could be expanded into a transformer substation in the future. In the same year, the old Kalajoki substation was demolished and replaced by the new Jylkkä substation. The substation was expanded in 2022 to cater for the needs of wind power with the addition of a third main transformer. The new Kärppiö transformer substation was built in Teuva in 2022. The Valkeus transformer substation will be completed in Pyhäjoki in 2023, along with the Arkkukallio transformer substation in Isojoki and the 110 kV Julmala substation in Seinäjoki. A second main transformer will also be added to the Tuovila substation in 2023, and the ageing 110 kV switchgear in Alajärvi will be modernised with the addition of a second main transformer.

The new Hirvisuo transformer substation was built in Kokkola in 2016 to replace the 220/110 kV transformers at Ventusneva. The Hirvisuo substation was expanded in 2019 with the addition of a second main transformer. In 2020, new gas-insulated switchgear was commissioned in Raahe to replace the Rautaruukki substation as a main grid substation.

The north–south power transmission capacity was increased in 2022 with the completion of the Forest Line, which is the fifth 400 kV connection through Cross-section Central Finland. The Forest Line runs from Oulujoki all the way to Petäjävesi. At the same time, the Pysäysperä transformer substation was completed along the Forest Line in Haapajärvi to enable the connection of wind power and improve the system security of the distribution network. In addition, a new 400 kV switchgear plant replaced the ageing 220 kV switchgear in Petäjävesi.

In Central Finland, the ageing Mänttä substation was modernised in 2016 near the existing substation, and the new 400 kV switchgear in Alajärvi was completed at the end of 2017. 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. The transmission capacity and system security of the 110 kV main grid between Koivisto and Vihtavuori were improved by constructing another connection in 2018 in conjunction with the commissioning of the Äänekoski bioproduct mill.

The new 110 kV gas-insulated substation in Jyväskylä was commissioned in 2019 to maintain system security in the Jyväskylä region. The investment replaced the ageing Keljo substation. When the new substation was built, transmission line connections were made from the Jyväskylä substation to the Petäjävesi, Kauppila, and Rauhalahti substations.

Development plan for the Raahe-Kokkola region

Transmission line projects

As wind power production increases on the west coast, new transmission lines to Southern Finland will be needed. The next 400 kV reinforcement on the west coast is due for completion in 2027, when a new connection will be built to Alajärvi from the Jylkkä substation in Kalajoki. The investment will increase the transmission capacity and system security in the region, make it easier to obtain maintenance outages on existing transmission lines and improve voltage stability. The transmission line has been planned with a two-circuit structure, and the tower structure will offer the option of installing a 110 kV line on the lower arm.

Raahe–Kokkola

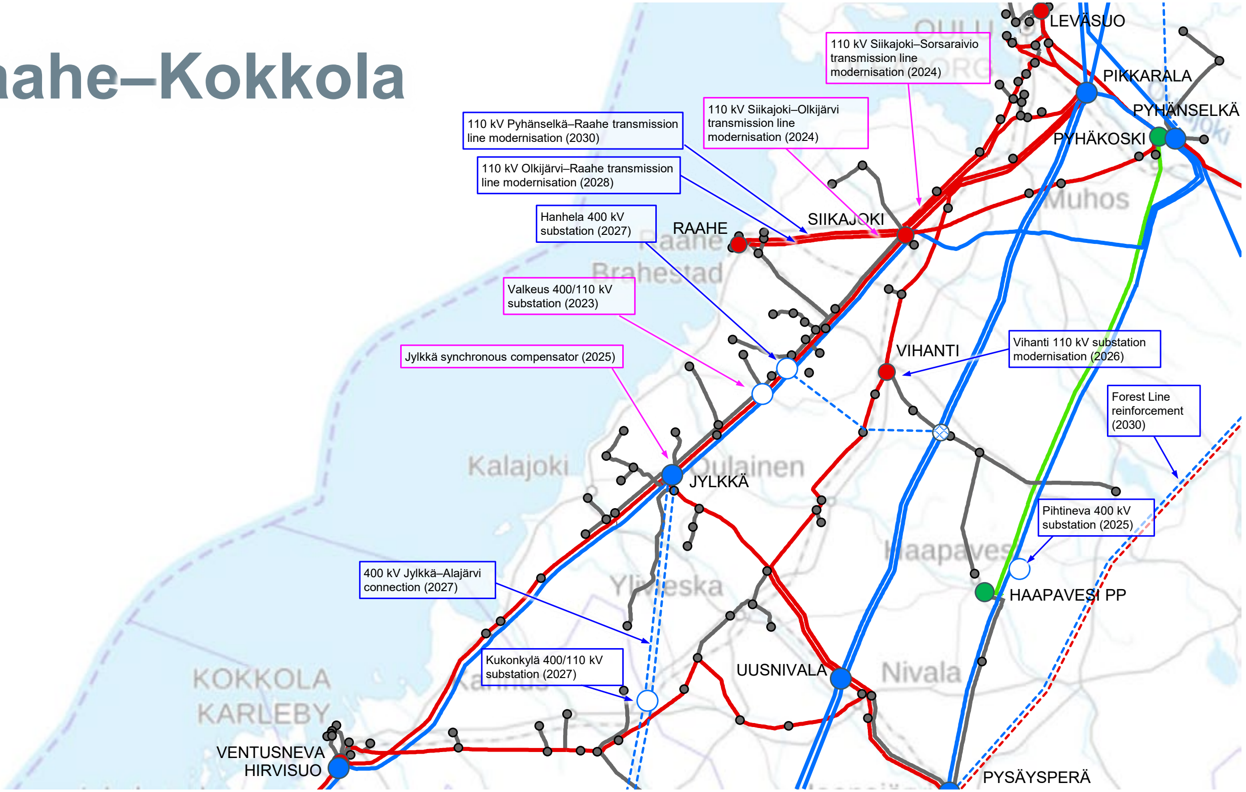


Figure 13. Development plan for the Raahe-Kokkola region.

On the 110 kV Pikkarala–Siikajoki A connection, the section from Siikajoki to the Sorsaraivio disconnector substation will be modernised so that the transmission capacity corresponds to the rest of the transmission line in 2024 as wind power production increases in Siikajoki. The 110 kV Siikajoki–Raahe–Pyhanselkä connection will be modernised in parts as required by the condition of the line: the Siikajoki–Olkijärvi section will be modernised in 2024, Olkijärvi–Raahe in 2028, and Pyhänselkä–Raahe in 2030.

Substation projects

New substations will be built along the new 400 kV Jylkkä–Alajärvi transmission line to connect wind and solar power plants to the grid. One of these, the Kukonkylä transformer substation, is planned for construction in the area between the municipalities of Sievi and Kannus in the Raahe-Kokkola region in 2027.

The Hanhela substation is planned for construction in Pyhäjoki to enable higher electricity consumption at the Raahe steelworks and connect offshore wind power to the grid. If necessary, a new 400 kV connection will also be built from Hanhela to the Lumijärvi substation, which may be built in Raahe. The Pihtineva substation is planned for construction in Haapavesi in 2025 to connect wind power and the industries in the area to the grid.

Development plan for the Kokkola-Seinäjoki region

Transmission line projects

A 400 kV connection will be built from the Jylkkä substation in Kalajoki to Alajärvi to enable the transmission of wind power from the west coast. The transmission line will be completed in 2027. The investment will increase the transmission capacity and system security in the region, make it easier to obtain maintenance outages on existing transmission lines and improve voltage stability. The transmission line has been planned with a two-circuit structure, and the tower structure will offer the option of installing a 110 kV line on the lower arm. The transmission line will be extended from Alajärvi to the Toivila substation in Jämsä by 2028.

Kokkola–Seinäjoki

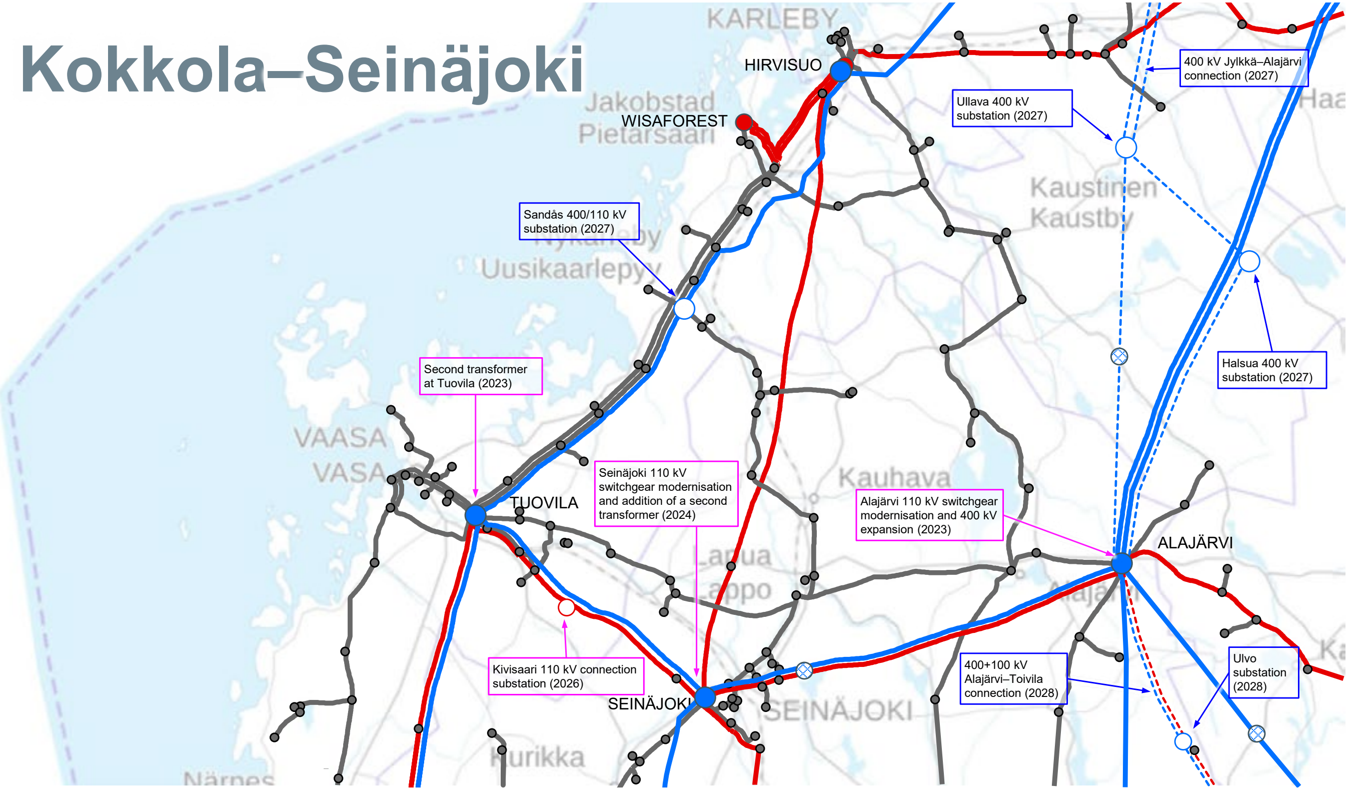


Figure 14. Development plan for the Kokkola-Seinäjoki region.

Substation projects

The 110 kV Seinäjoki switchgear will be converted to gas-insulated switchgear in 2024 as appropriate for its condition. A second 400/110 kV transformer will be added to Seinäjoki to enable new customer projects to be connected to the grid. The Kivisaari substation will be built along the 110 kV transmission line between Seinäjoki and Tuovila in 2026, and the Sandås substation will be built in Nykarleby in 2027. Both substations will be built to connect wind power to the grid, while the Sandås substation will also facilitate the development of the distribution network in the region.

The Ullava and Halsua substations will be built along the 400 kV Jylkkä–Alajärvi–Toivila line in 2027 to cater for wind power.

If necessary, the Laurinneva transformer substation will be built along the transmission line to enable wind and solar power to be connected to the grid and facilitate the development of the distribution network in the region. The Ulvo substation, planned between Alajärvi and Petäjävesi, will use series compensation on the Jylkkä–Toivila section. It will also enable the connection of wind and solar power to the grid.

If necessary, the Löytökangas substation is planned for construction along the existing 400 kV Alajärvi–Kangasala line to enable wind and solar power to be connected to the grid. The Kotaneva substation is also planned along the 400 kV Seinäjoki–Alajärvi line to connect wind power to the grid.

Seinäjoki–Pori

Development plan for the Seinäjoki-Pori region

Transmission line projects

A 400 kV connection will be built from the new Åback substation in Kristinestad to the new Nokia substation to enable the connection of wind power projects in the area between Pori and Vaasa. The transmission line will be completed in 2028.

Substation projects

The new Honkajoki substation is planned along the existing 400 kV Seinäjoki–Ulvila transmission line, with commissioning planned for 2025. The substation will be built to connect the planned wind power production in the area to the grid. The new Åback substation will be built in Kristinestad to cater for the new 400 kV transmission line to be built to Nokia. A new substation will also be built in Nokia to replace the ageing 110 kV switchgear in Melo. The Lähteenkylä

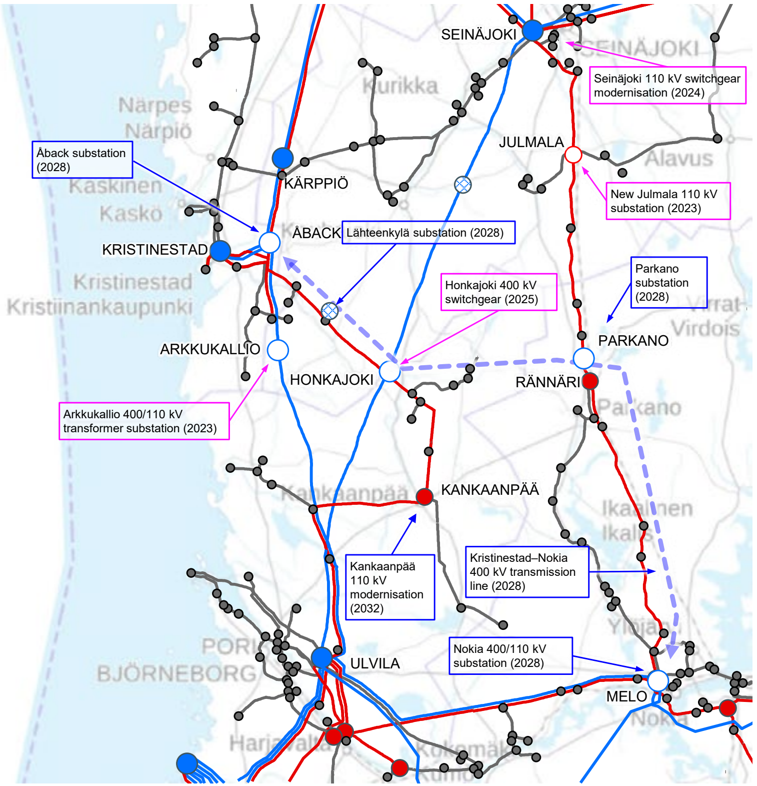


Figure 15. Development plan for the Seinäjoki-Pori region.

and Parkano substations will also be built along the new 400 kV Kristinestad–Nokia transmission line. The Sahankylä substation is planned for construction along the 400 kV Seinäjoki–Ulvila line to connect wind and solar power to the grid.

The 110 kV Seinäjoki switchgear will be converted to gas-insulated switchgear in 2024 as appropriate for its condition. A second 400/110 kV transformer will be added to Seinäjoki to enable new customer projects to be connected to the grid. The ageing 110 kV switchgear in Kankaanpää is due to modernisation in 2032.

Development plan for Central Finland

Transmission line projects

Central Finland has a large number of ageing 110 kV transmission lines built on wooden towers, and these will be renewed. The 110 kV Huutokoski–Kauppila–Hämeenlahti transmission line will be modernised in 2024, and the 110 kV Petäjävesi–Mänttä transmission line will be modernised in 2026.

The new 400 kV Alajärvi–Toivila line will be built to transmit wind power from the west coast to consumption centres in the south of Finland. The connection will be completed in 2028. The new transmission line will mostly be built in place of the existing 110 kV Alajärvi–Petäjävesi and Petäjävesi–Toivila connections. The existing 110 kV connections will be modernised and placed on the lower arms of the towers used for the 400 kV transmission line.

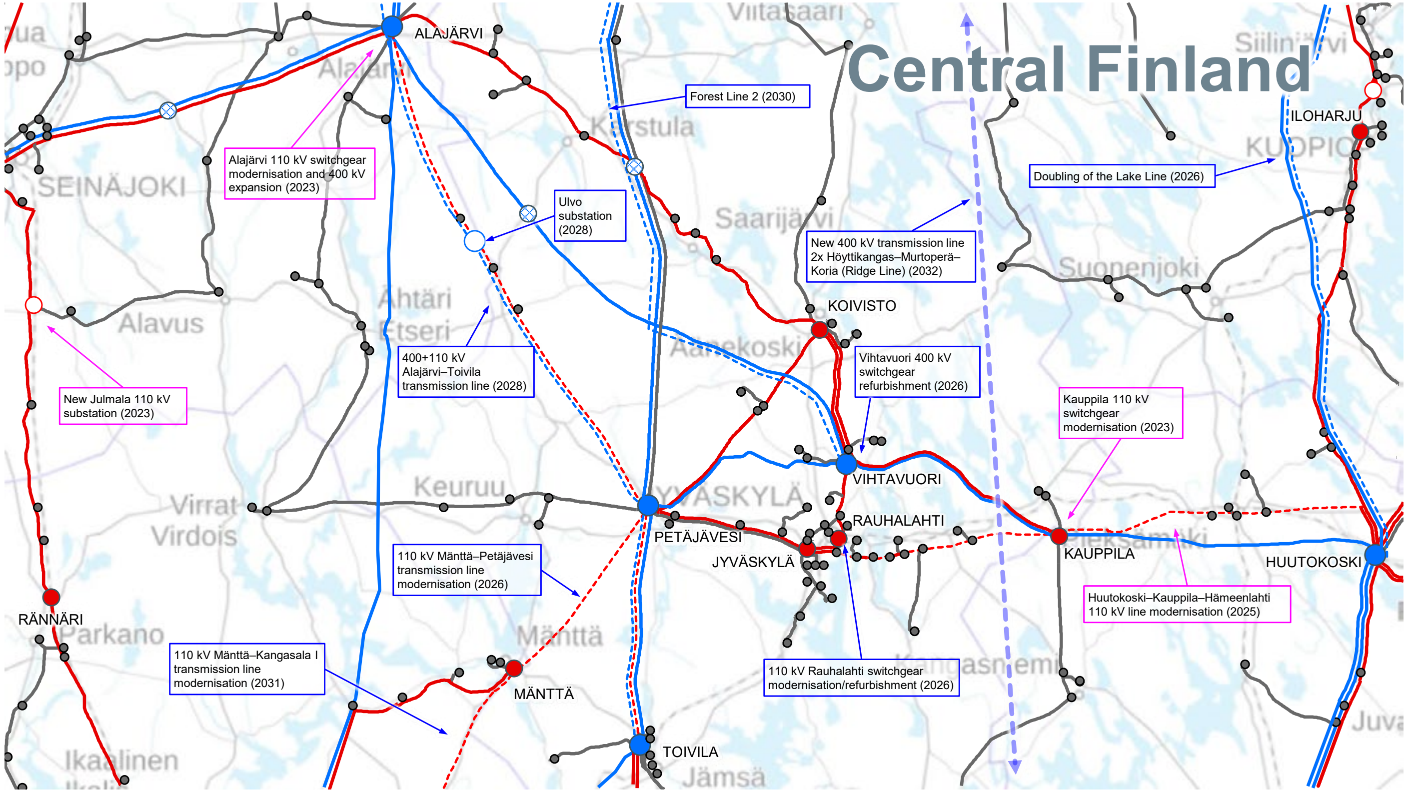


Figure 16. Development plan for the Central Finland region.

The planned strengthening of the Forest Line, required to increase the transmission capacity over Cross-section Central Finland and connect new electricity production facilities to the grid, will be completed in 2030. The new connection will run from the Pyhänselkä substation in Muhos to Central Finland.

Substation projects

The Kauppila substation will be modernised, as appropriate for its condition, in connection with the 110 kV Huutokoski–Kauppila–Hämeenlahti transmission line project in 2024. The Rauhalahti substation will be refurbished in 2026. The Ulvo transformer substation is planned for construction between Alajärvi and Petäjävesi in 2028 with series compensation for the new 400 kV Alajärvi–Toivila connection. The substation will connect wind and solar power in the area to the grid. In addition, the Leppärinne transformer substation is planned for construction in Saarijärvi along the Forest Line in 2030 to connect wind and solar power to the grid. If necessary, the Löytökangas substation is planned for construction along the existing 400 kV Alajärvi–Kangasala line to enable wind and solar power to be connected to the grid.

Southern Finland

Description of the region

The Southern Finland planning area covers about one-sixth of Finland's territory. The region is densely populated: approximately three million people live in the planning area. The strong 400 kV network in the region enables the electricity produced in Northern Finland and on the west coast to be reliably transmitted to consumption centres in Southern Finland. The planning area also includes five HVDC cross-border connections, of which the 400 MW Fenno-Skan 1 and 800 MW Fenno-Skan 2 are in Rauma, connecting Finland's main grid with the network in Southern Sweden. The cross-border connections to Estonia are the 350 MW Estlink 1 and the 650 MW Estlink 2, which connect to Finland's main grid at the Espoo and Anttila substations. In addition, an HVDC transmission link runs between the Naantalinsalmi substation and Åland, serving as a reserve connection to safeguard the power system of Åland in the event of a disturbance.

The Southern Finland planning area is energy-intensive – approximately two-thirds of Finland's electricity consumption is located south of Tampere. Electricity consumption is mainly concentrated in the Helsinki metropolitan area and other larger urban areas, including Turku, Lahti and Tampere. The electricity deficits of urban areas will increase significantly as the production of heat at combustion plants is increasingly replaced by solutions such as electric boilers, further emphasising the need for strong and reliable electric transmission connections. The electricity network in the region is under continuous development in line with production and consumption forecasts in collaboration with the local distribution system operators.

The hydrogen economy will be a major factor affecting electricity consumption in the planning area, along with the electrification of heating. Several investments in hydrogen production and refinement are planned in Southern Finland. Finland's first industrial-scale green hydrogen production plant will be completed in Harjavalta in 2024. Other green hydrogen production plants with several hundreds of megawatts of potential are planned in the coming years in locations such as Naantali, Tampere, Lahti and the Helsinki metropolitan area. The electrification of industry will also increase the region's electricity consumption substantially. For example, an electrolyser is planned for construction at the Porvoo oil refinery to replace hydrogen produced using natural gas. A steelworks utilising electrolysis is planned for Ingå, with electricity consumption estimated in the hundreds of megawatts.

The electricity production capacity in Southern Finland consists mainly of nuclear power – all of Finland's nuclear power plants are in the planning area. In addition to nuclear power, electricity is produced at industrial and district heating CHP plants, condensing power plants, hydro power plants, and wind power plants. The volume of fossil-based

About two-thirds of Finland's electricity consumption is located to the south of Tampere.

electricity and heating production is declining. For example, the Hanasaari power plant in the Helsinki metropolitan area was shut down in 2023. The last coal-fired power plants in the Helsinki metropolitan area will be decommissioned according to plan in the coming years. Peak electricity consumption in the Helsinki metropolitan area is forecast to grow substantially by 2030 as local production declines.

In the future, Southern Finland's electricity production will increasingly consist of renewable energy. Wind power enquiries for over 5 gigawatts of output and solar power enquiries for over 10 gigawatts of output have been submitted in the area. In total, these projects would have a peak output almost five times that of a nuclear power plant. In addition, offshore wind power enquiries with significant production capacity have been submitted in the region. If they come to fruition, these projects will be executed in the 2030s. Solar power plants can be built on an industrial scale much more quickly, so the solar power capacity may increase significantly in the coming years.

Recent investments in the Southern Finland grid

Many investments have been made in the main grid in the Pori and Rauma region in the last two decades. The 400 kV and 110 kV main grid in the region was significantly strengthened to connect the third nuclear power plant at Olkiluoto and facilitate the connection of wind power projects. The Fenno-Skan 2 cross-border connection was built to reinforce the transmission capacity between Sweden and Finland. The transformer capacity in the planning area has also been boosted by adding new main transformers to substations. The most recent projects included the modernisation of the Olkiluoto A substation and the construction of the new Uusikaupunki 110 kV substation in 2019.

The main grid in the Häme region was strengthened due to increased transmission needs and the ageing of the network. The new Lavianvuori substation was built in Valkeakoski in 2015 to increase transformer capacity in the Tampere region to address the growing electricity deficit. The old 110 kV Vanaja–Tikinmaa transmission line, which was in poor condition, was modernised in 2018, improving system security and transmission capacity in the Hämeenlinna area. The final section of the Hikiä–Orimattila transmission line connection, built to replace the Rautarouva ("Iron Lady"), the first backbone line in the main grid dating back to the 1920s, was completed in 2019 when the transmission line was modernised with a 400+110 kV structure. At the same time, a new 110 kV substation was built in Orimattila. The entire Rautarouva connection from Turku to Imatra has now been replaced by a new transmission line.

Most of the ageing network in Southwest Finland has been modernised. In 2015, the 110 kV switchgear in Naantali was replaced by the new Naantalinsalmi substation. At the same time, ÅL-Link, a new submarine cable between Åland and mainland Finland, was connected to the Naantalinsalmi substation. The transmission line between Forssa and Lieto was renewed with a 400+110 kV double-circuit tower transmission line in 2018. The new transmission line serves regional electricity transmission needs in Southwest Finland and improves the main grid system security in the area. The Forssa substation was expanded and refurbished in conjunction with the transmission line project.

The transformer capacity in the Uusimaa region was increased in 2017 with the addition of transformers to the Espoo and Länsisalmi substations. In recent years, the Ingå, Nurmijärvi, Porvoo and Ruotsinkylä substations have been refurbished and modernised. The modernised 110 kV Tammisto and Virkkala gas-insulated switchgear plants were completed in 2022. The Virkkala substation uses new SF6-free GIS technology.

Development plan for Southwest Finland

A new network is under construction in the Southwest Finland region to meet the needs of regional consumption centres. The ageing network in the area is also being modernised.

Transmission line projects

A new 400 kV connection from Huittinen to Forssa will be completed in 2025. The transmission line will improve the main grid's energy-efficiency and system security and enable better maintenance and fault outages without harming the security of the power system. In addition, the ageing 110 kV Kolsi–Forssa transmission line will be modernised on the lower arm of the transmission line between the Huittinen and Forssa substations. The new 110 kV Metsämaa substation will be connected to the transmission line.

Southwest Finland

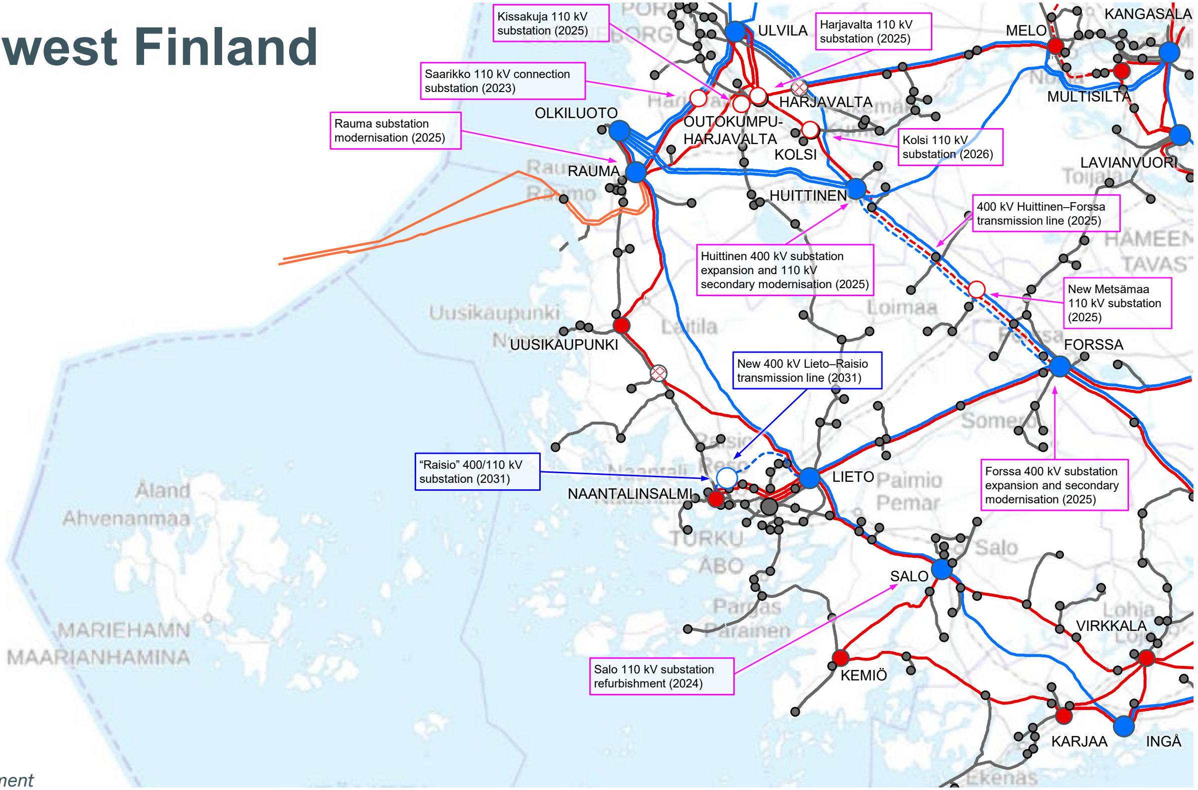


Figure 17. Development plan for the Southwest Finland region.

Electricity consumption is increasing in the Naantali and Turku region, so greater electricity transmission capacity is required. A new 400+110 kV transmission line is planned from the Lieto substation to Raisio, with commissioning scheduled for 2031. The new transmission line will connect to a new transformer substation to be constructed in Raisio. From there, the 400 kV connection could be extended towards Rauma if further transmission capacity is needed between Rauma and Lieto – for example, if offshore wind power projects are carried out.

Substation projects

Ageing substations in Southwest Finland will be modernised. The refurbishment of the 110 kV switchgear in Salo will be completed in 2024. The following year will see the completion of the Rauma substation modernisation and the new Metsämaa 110 kV switchgear on the 110 kV Kolsi–Forssa transmission line. The Metsämaa substation will increase regional system security and enable electricity production projects in the region to be connected to the main grid.

Three new substations will be built in the Pori and Rauma areas to replace ageing substations owned by customers. At present, electricity is transmitted in the main grid through substations owned by customers, hindering operation and maintenance measures. In addition, the Electricity Market Act requires the transmission system operator to own the installations needed to transmit electricity in the main grid. Changes of ownership are carried out when substations are modernised. The construction of the Harjavalta, Kolsi and Kissakuja substations is scheduled for 2025 and 2026. The new substations will have gas-insulated switchgear, which will help to reduce the land-use impacts of the new substations.

Häme development plan

The main grid will be strengthened in the Häme planning area to cater for the growth in consumption demand. A new main transmission network will be built in the area, and the ageing network will be modernised.

Transmission line projects

There are a few ageing transmission lines on wooden tower structures that will be modernised in the Häme planning area: the 110 kV Melo–Multisilta transmission line will be modernised in 2029 when the new Nokia transformer substation is completed, the ageing Melo–Rännäri 110 kV transmission line will be modernised in 2030, and the older of the two 110 kV transmission lines between Kangasala and Mänttä – the eastern connection – will be modernised in 2031.

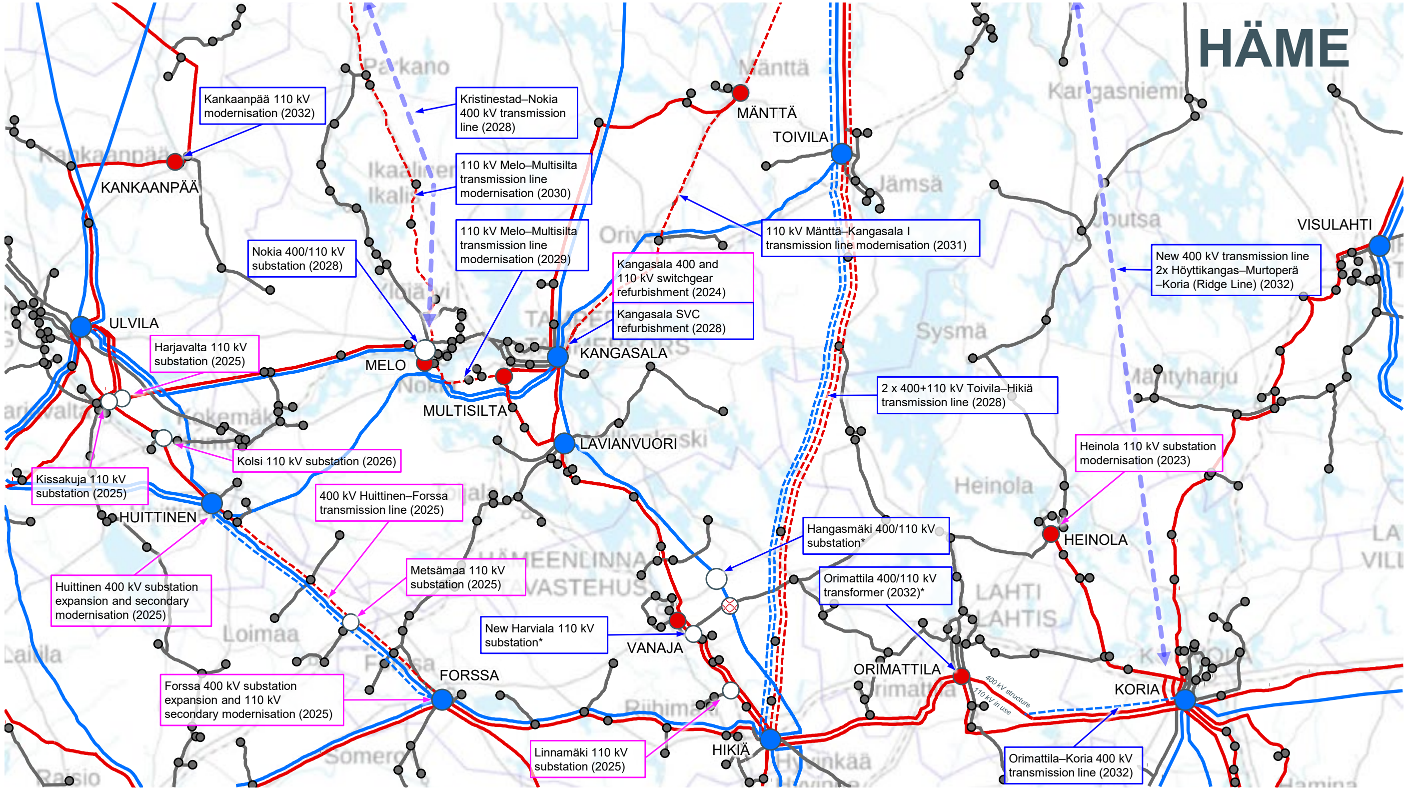


Figure 18. Development plan for the Häme region.

A 400 kV transmission line is planned from Kristinestad to the new Nokia substation to help transmit the wind power production from Western Finland to consumption centres in Southern Finland. The transmission line is undergoing an EIA procedure to assess the environmental impacts of alternative routes. In connection with the construction of the transmission line, a new 400/110 kV transformer substation will be built in Nokia to replace the old 110 kV Melo substation. The new substation will increase the electricity transmission capacity in the Tampere region and improve system security.

The Hikiä substation in Hausjärvi will become an important main grid hub when new transmission lines are built to the area from the north and the south. From the north, two new 400+110 kV transmission lines will be built from the Toivala substation to Hikiä in 2028 to transmit electricity production from the north to consumption centres in the south. From Hikiä to the south, a new 400 kV connection will be built to the Länsisalmi substation in Vantaa in 2030 to enable the increase in electricity consumption in the Helsinki metropolitan area. A second 400 kV connection from Hikiä to the south – the Hikiä–Ingå transmission line – will be built in 2031. Both transmission lines are being planned with a two-circuit structure in case the required transmission capacity is larger than projected.

The Ridge Line will be built with a dual 400 kV structure from the Murtoperä substation, which will be built in Pyhäjärvi or possibly in Kiuruvesi, to Southern Finland in 2032. In connection with the project, a 400/110 kV transformer will be added to the Orimattila substation. In addition, a 400 kV transmission line is planned between Orimattila and Koria. The transmission line is part of the Hikiä–Koria 400 kV connection, which is being constructed to increase transmission capacity in the east–west direction. The section between Hikiä and Orimattila has already been built with a 400 kV structure, so the operating voltage on this section of the transmission line can be switched from 110 kV to 400 kV.

Substation projects

Ageing substations will be modernised in the Häme planning area in the coming years. The modernisation of the 110 kV Heinola substation will be completed towards the end of 2023. The Kangasala substation is undergoing an extensive refurbishment project to maintain the condition of the station. The project is due for completion in 2024.

The new Linnamäki substation will be completed in Tervakoski in 2025 to serve the increased electricity consumption in the area and improve system security. Electricity consumption is increasing in the area around Hämeenlinna. For example, the Tervakoski paper mill and SSAB's Hämeenlinna works are becoming electrified, so more transmission capacity is required in the Hämeenlinna region. A new transformer substation is planned for construction in Hangasmäki and a new GIS plant in the Harviala area to develop the main grid in the region.

In connection with the construction of the 400 kV Åback–Melo transmission line in 2028, a new 400/110 kV transformer substation will be built in Nokia to replace the old 110 kV Melo switchgear. The new transformer substation will enable increased electricity consumption in the Tampere region. 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. The new 400/110 kV Parkano transformer substation is planned in the area to connect electricity production facilities to the grid. The substation will also be completed in conjunction with the construction of the 400 kV Åback–Melo transmission line.

Development plan for the Helsinki metropolitan area

New 400 kV connections will be built in the Helsinki metropolitan area planning area to help transmit the electricity produced in Northern and Western Finland to consumption centres in Southern Finland. In addition, ageing substations in the area will be modernised, and the regional main grid will be strengthened.

Electricity production 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 transmitted to other parts of Finland via Fingrid's 400/110 kV transformers and main 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 currently occur in the summer. In the Helsinki metropolitan

Figure 19. Development plan for the Uusimaa area.

area, electricity consumption is increasing and electricity production is declining. The growth in electricity consumption is due to several factors, including the reduction in electricity production based on conventional combustion power plants, new heating solutions, data centre projects, and the electrification of transport.

Transmission line projects

As consumption increases, the transmission capacity of Helsinki's 110 kV high-voltage distribution network may be insufficient. Fingrid is planning to develop the Helsinki metropolitan area network in collaboration with electricity production companies and distribution system operators in the region. However, it is difficult to build new overhead wires in Helsinki. To ensure the supply of electricity for functions important to society and residents in the region, Fingrid will build a new 400 kV cable link from the Länsisalmi substation in Vantaa to the new Vanhakaupunki substation in Viikki, Helsinki. The connection will be completed in 2026. The cable will be built into a trench and protected. Planning will also take into account the possibility of installing a second cable link at a later date. In the future, the cable link could be duplicated to ensure an uninterrupted power supply even in the event of faults and maintenance outages as transmissions increase. The Vanhakaupunki substation in Viikki has been selected as the terminal station for the cable link because of its central location in the regional distribution network.

In addition, a new 400 kV connection from Hausjärvi to the Anttila substation in Porvoo and onwards to the Länsisalmi substation in Vantaa will be completed in 2030 to enable an increase in electricity consumption in the Helsinki metropolitan area. The 400 kV connection from the Hikiä substation in Hausjärvi to the Ingå substation will be completed in 2031. This connection will enable an increase in electricity consumption in the Ingå region and boost the transmission capacity in preparation for the Estlink 3 HVDC transmission link. Estlink 3, the third cross-border connection between Finland and Estonia, will be completed in 2033. The ageing 110 kV Kopula–Nurmijärvi transmission line will be modernised in 2024 and 2025.

Substation projects

The Espoo substation is important in terms of electricity transmission in the Helsinki metropolitan area. The substation will be refurbished in 2024 to maintain a good standard of system security. As electricity consumption grows in the western parts of the Helsinki metropolitan area and production decreases, new transformer capacity will be required in the area. To this end, Fingrid will build the new 400/110 kV transformer substation in Espoo in 2025 along the 400 kV Espoo–Tammisto transmission line. In addition, the new Vanhakaupunki substation will be built in Viikki, Helsinki, to accommodate the 400 kV Helsinki cable in 2026, and the Länsisalmi substation will be expanded. There are also many electricity consumption and production projects in the area, and several substation expansions will be required to connect them to the main grid.

Fingrid is planning to develop the Helsinki metropolitan area grid in cooperation with electricity production companies and distribution system operators in the area.

Summary of investments in the main grid

In recent years, Fingrid's investments have focused mainly on the domestic network, and a record number of investments have been underway. From 2024 to 2033, Fingrid is planning an accelerating rate of investments. It will invest EUR 4 billion, averaging EUR 400 million every year. Fingrid's annual depreciation has been around EUR 100 million, but it will increase in the future. Figure 20 presents Fingrid's investment levels from 2001 to 2033.

Fingrid's investment levels have risen main grid as a consequence of the main grid reinforcements demanded by the energy revolution. Approximately 80% of Fingrid's investment costs are new investments. The large proportion of new investments is mainly due to the large number of new north-to-south 400 kV connections, cross-border connections, compensation

Investments by network and by year

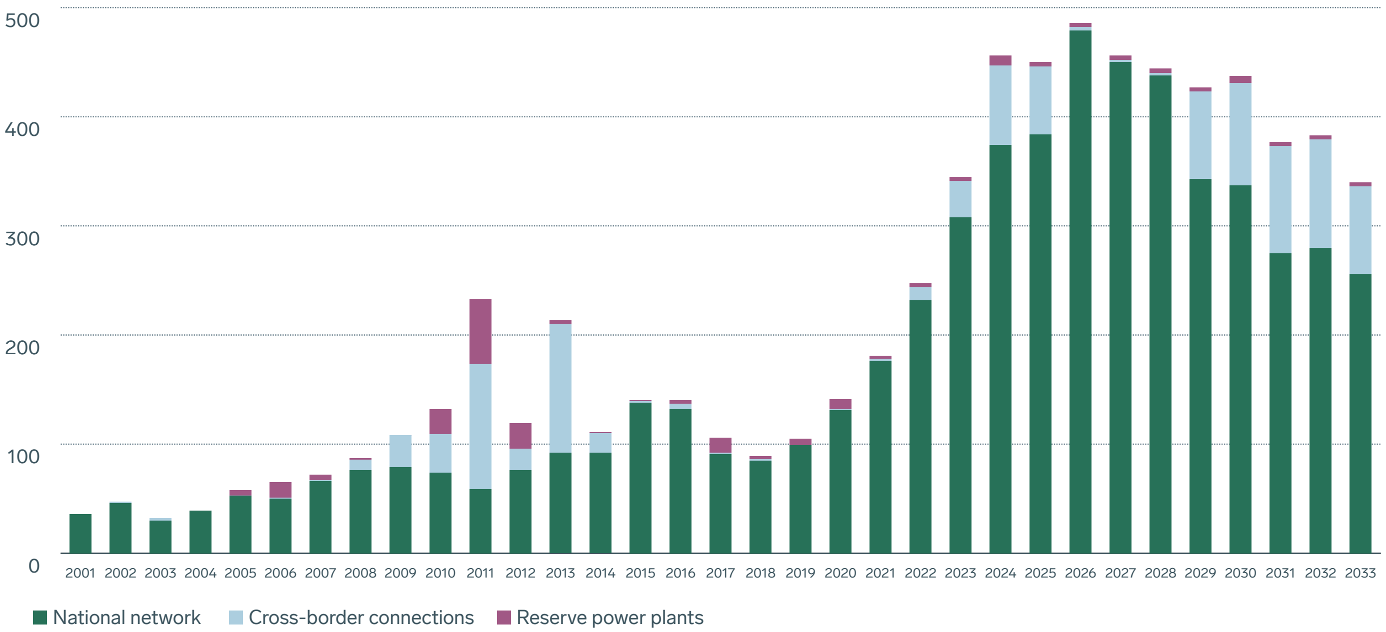


Figure 20. Fingrid's investments from 2001 to 2033.

solutions, and substation investments. Most new electricity production facilities are being built in Western and Northern Finland, while electricity consumption and electrifying industry is mainly concentrated in Southern Finland. This increases the need for strong transmission connections in the main grid. In addition, new industrial and electricity production projects require new substations for connections.

In addition to new investments, substation refurbishments will take place, and ageing 110 kV transmission lines will be renewed during the planning period. The main grid does not have a maintenance backlog, and the grid has been 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 21 illustrates how Fingrid's grid investment costs over the next 10 years will be distributed between substation, transmission line, reserve power and HVDC projects. Figure 22 shows the proportions of new and replacement investments.

Figure 23 presents Fingrid's investments from 2024 to 2033. Approximately 3,800 kilometres of new 400 kV transmission lines will be built. These transmission lines will create a strong main transmission grid, supplemented by 110 kV lines. Approximately 2,300 km of 110 kV transmission lines will be built over the next ten years. In addition, 128 large substation projects will be carried out. Several smaller refurbishment projects and numerous projects will also be executed due to new customer requirements.

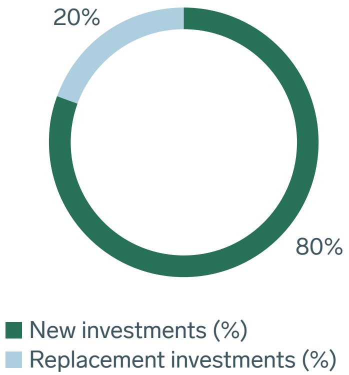


Figure 21. The distribution of investment costs between substation, transmission line and HVDC projects.

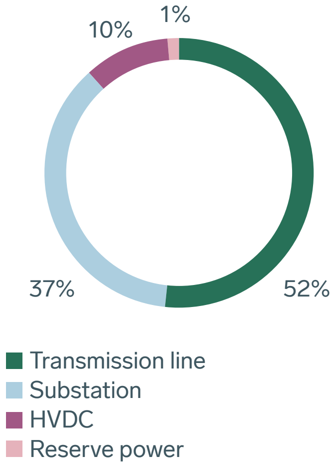


Figure 22. The distribution of investment costs between new and replacement investments.

The development plan involves some uncertainties related to the energy revolution and the pace of change in the electricity production structure. For example, the amounts and locations of wind power facilities and new, electricity-intensive industrial plants and the rate of electrification of society will have a major impact on Fingrid's investments. Fingrid is cooperating closely with customers and preparing for possible new connections. It is likely that more substation extensions and new 400/110 kV transformer substations will be implemented than previously expected due to customer needs that will only become apparent in the future.

Fingrid updates its investment plan as a continuous process in step with the changing operating environment. For the latest information about the investment plan, please visit Fingrid's website or contact Fingrid directly. Fingrid will publish its next main grid development plan in 2025.

2024–2025 in figures

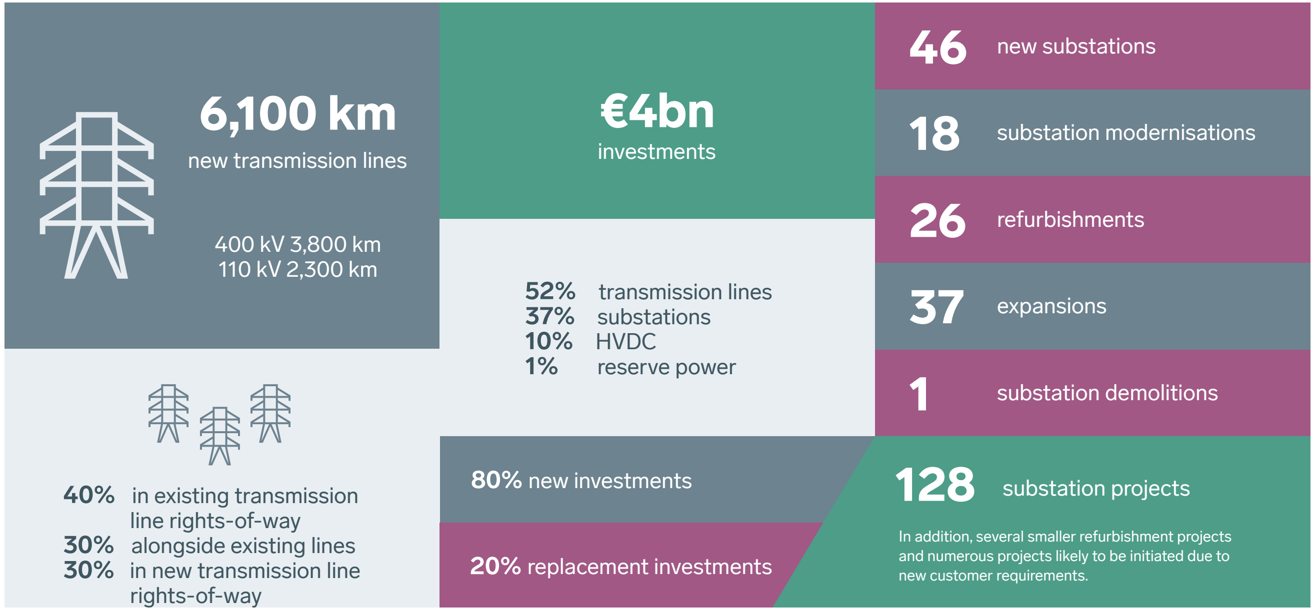


Figure 23. The development plan in figures.

05

Changes in the operating environment and future outlooks

The energy sector plays a key role in mitigating climate change. The structure of electricity production is changing as the use of renewable energy increases and adjustable fossil power decreases. The amount of wind and solar energy will increase rapidly. At the same time, electricity is replacing fossil fuels in industry and transport. The change in the electricity production structure will give rise to occasional shortages of power, flexibility, system inertia and short-circuit power. While this will pose an additional challenge for the power system, it will also offer business opportunities for flexible production and consumption and, for example, grid energy storage.

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

Society is becoming more electrified and dependent on electricity. Consequently, serious disturbances in the electricity supply have become one of the most important security threats to society. 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 long-term 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 Electricity System Vision, which was published in January 2023. The main grid development plan largely focuses on developments in the next ten years.

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 produced using renewable energy sources is an effective means of reducing emissions from industry, heating, and transport. In Fingrid's estimation, the emission-reduction targets will also result in a structural increase in electricity consumption. However, this can only succeed if the technologies required by the transformation, such as electric cars, heat storage facilities, and new industrial processes, are competitive. If the carbon-neutrality targets are to be achieved, development must first accelerate with the help of various investment subsidies, such as electrification aid for industries and grants from the EU's RRF. Increased demand for clean electricity also lays the foundations for offering electricity on market terms. It is common for direct power purchase agreements (PPAs) to be made between parties such as industrial operators and wind power producers.

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 significant opportunities for companies operating in Finland to produce green 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.

Finland has set itself the target of becoming carbon neutral by 2035.

The electrification of society and the outlook for development

Society's use of energy will be transformed by the shift from traditional, mainly combustion-based energy to emission-free green electricity. The energy economy of the future will largely be a hydrogen economy, leading to significant emission reductions among conventional smokestack industries thanks to the transition to cleanly produced hydrogen. However, the construction of networks of pipelines and storage facilities required for an extensive hydrogen infrastructure will inevitably take time. As such, the initial benefits will be felt by countries and regions where hydrogen and the requisite electricity production can be located close to hydrogen consumption sites. This puts Finland in a competitive position in the new industrial era. Finland has excellent opportunities to develop new, inexpensive and emission-free electricity production close enough to consumption sites, as well as a strong, comprehensive electricity transmission grid to connect new projects.

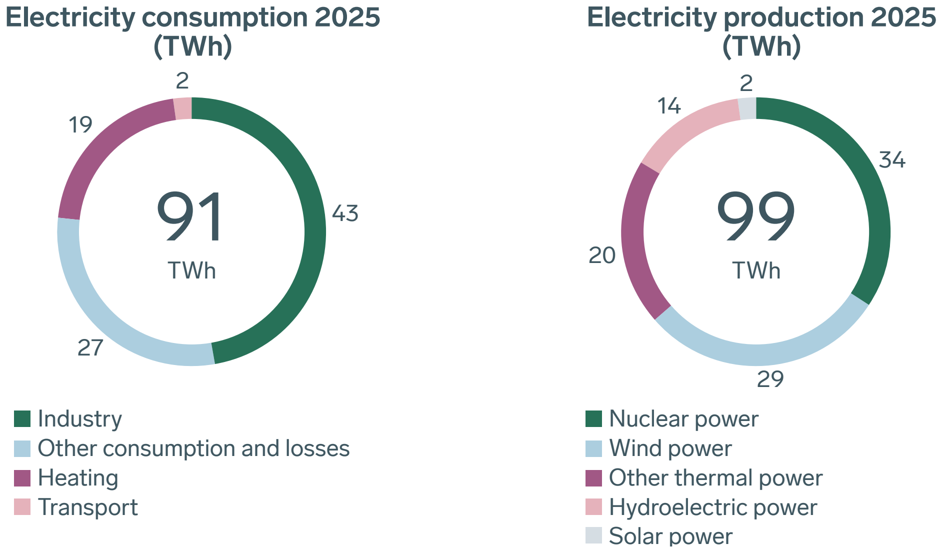


Figure 24. Electricity consumption and production forecast for 2025.

In the future, electricity consumption will have substantial growth potential, much of which will not yet be realised this decade. Fingrid estimates that electricity consumption will increase by 125–140 TWh by 2030, driven primarily by industry. The growth in consumption will be affected by climate targets and, consequently, Finland's attractiveness as a place to invest for industries relying on clean electricity.

Figures 23 and 24 summarise the trends in the power balance according to the Best Estimate for 2025 and 2030. The following sections provide more details on the consumption and production sectors.

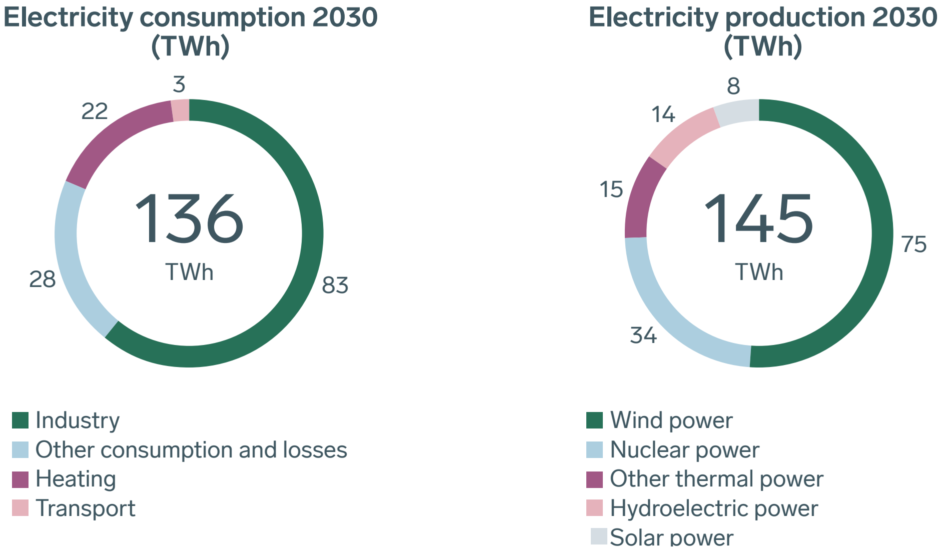


Figure 25. Electricity consumption and production forecast for 2030.

The electrification of industry

The action required to enable low-carbon industry and the increase in the need for electricity is covered in depth in the industrial low-carbon roadmaps. The main grid development plan makes preparations for the realisation of ambitious electrification scenarios. These scenarios also support Finland's strong capacity to produce large volumes of clean, competitive electricity, which will make Finland a significantly more attractive place to invest. The increase in industrial electricity consumption – by 40–50 TWh from 2023 to 2030 – will be the main driver of the rise in Finland's electricity consumption and the size of its electricity system.

The background to the increases in industrial electricity consumption varies by industry. 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. 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.

Other electricity consumption trends

Electricity consumption in heating is expected to rise by 3–5 TWh based on the increase in the number of heat pumps and electric boilers. Large heat pumps and electric boilers can replace combustion in the production of district heating, and similarly, property-specific heat pumps can replace oil and district heating. The use of high-power heat pumps in industries and service sectors is also on the rise.

The greatest growth in electricity consumption will occur in cities where electric heating is replacing combined heat and power production using fossil fuels. This will cause electricity consumption to rise while electricity production declines. In practice, this will require the reinforcement of the electricity supply to growth centres.

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 more efficient than internal combustion engines. If the entire passenger car fleet in use (2021: 2.8 million vehicles) were electrified, electricity consumption 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 500,000 to 1,000,000, so electricity consumption would increase by 1.5–3 TWh.

Electrification of heavy vehicles and an increase in rail transport would also raise electricity consumption, but the impact is expected to be limited this decade. It should be noted that if vehicles were powered by hydrogen produced using Finnish electricity or synthetic fuels derived from such hydrogen instead of being powered directly by electricity, the resultant conversion losses and lower efficiencies would lead to higher overall electricity consumption in Finland.

Other electricity consumption is not expected to change significantly. Electricity consumption will decrease among households and the service sector thanks to higher energy efficiency, but the projected population growth will increase consumption. Moreover, as electricity transmission increases, the losses arising in the grid will also increase. These factors are estimated to offset the impact of each other on average, so electricity consumption in all sectors except industry, heating and transport is not expected to change significantly overall.

The largest rise in electricity consumption will occur in urban areas.

Outlook for electricity production

Total electricity production in Finland will increase substantially. This will enable higher electricity consumption and allow for the cross-border trade in electricity to balance out and, ultimately, for Finland to become a net exporter. The volume of wind power will increase particularly rapidly, and it is expected to become the largest form of electricity production in Finland sometime this decade. Finland appears to be an attractive place to build wind turbines, especially for onshore wind power. There are several offshore wind power projects, and the number is rising sharply. The volume of solar power is also beginning to increase rapidly. Hydro power output is expected to remain at the level seen when the Olkiluoto 3 nuclear power plant started up. The volume of thermal power, consisting of combined heat and power and condensing power plants, is expected to decline as the use of fossil fuels for electricity production decreases.

Onshore wind power

At the end of 2022, Finland's wind power capacity was 5,677 MW, and its annual output was 11.5 TWh[3], corresponding to nearly 17% of Finland's electricity production. The investment cost of wind power relative to the production output has fallen substantially over a long period, 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.

In the period to May 2023, Fingrid received connection enquiries for more than 200,000 MW of wind power, of which onshore wind power accounts for approximately 150,000 MW. Unlike many other European countries, Finland still has plenty of space for onshore wind power. The growth in onshore wind power will be based on the price competitiveness of wind power against other forms of production, the competitiveness of Finnish wind farms against other Nordic countries, the increase in electricity consumption and the interest of electricity buyers to procure wind power electricity using bilateral 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 almost 2,000 MW per year in the 2020s, leading to a capacity of 18–23 GW by 2030. The corresponding energy production would be 60–80 TWh. If this comes to fruition, wind power will account for 40–60 per cent of total electricity consumption in Finland. Figure 26 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 longer term, the growth potential of wind power depends mainly on the increase in electricity consumption.

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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 become more 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 further increase the need to connect wind power to the grid and boost the north–south transmission capacity. A more even distribution of wind power locations across Finland, especially in Southern Finland and the southern parts of Eastern Finland below Cross-section Central Finland, would reduce the need for these investments.

[3] tuulivoimayhdistys.fi/ajankohtaista/tiedotteet/tuulivoimakapasiteetti-kasvoi-75-ja-toi-suomeen-yli-29-miljardin-investoinnit
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Wind power production capacity and electricity production

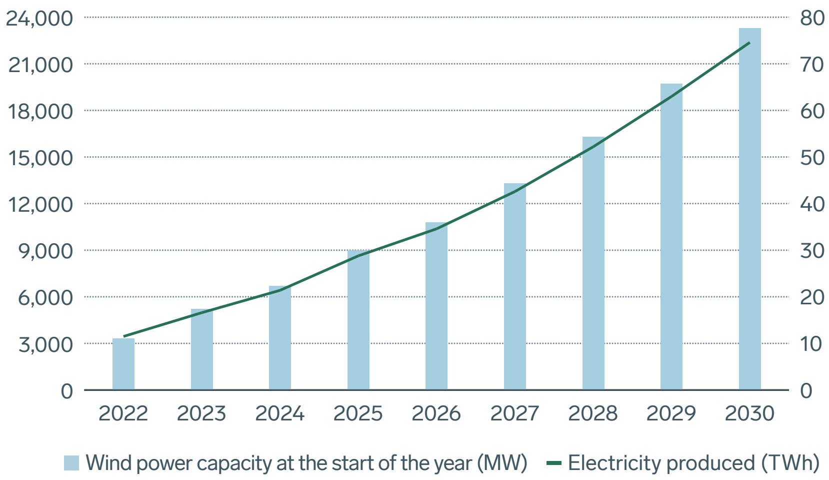

Figure 26. Wind power growth scenario.

Offshore wind power

Interest in the construction of offshore wind power is rising sharply in Finland and worldwide. Offshore wind power has a higher load factor, a steadier rate of production and larger turbine sizes than onshore wind power. Offshore wind power turbines are expected to become even larger in the coming years, making offshore wind power projects with higher construction and operating costs financially viable. Finland's coast is also relatively well suited to offshore wind power, and a large share of the country's electricity consumption is located near the coast. Offshore wind power projects are currently the largest individual industrial investments planned in Finland. Most of them are planned for implementation in the early 2030s.

In May 2023, Fingrid received offshore wind power enquiries for approximately 50,000 MW of output, corresponding to one-quarter of all wind power connection enquiries. The number of projects is just a fraction of the number of onshore wind power ones, but each project typically falls in the 1–3 GW range, equivalent to the output of one or two nuclear power plants. Offshore wind power projects are concentrated in the Gulf of Bothnia, stretching from the north of Åland to the end of the Bay of Bothnia. About half of the projects are in Finland's exclusive economic zone (EEZ), and half are in its territorial waters. Finland has not yet resolved the process for handing over project areas in the EEZ and granting exclusivity, but several exploration permits have been issued for the zone. Metsähallitus is the supervisory authority in charge of the territorial waters, and it is advancing with competitive tendering processes for the project areas it has prepared.

In terms of main grid development, the challenge with offshore wind power is the huge total output of such projects, their location on the west coast, which already has a production surplus, and the uncertainties surrounding the realisation, schedule and final size of the projects. All the offshore wind power projects on the west coast would require the main grid to be reinforced, meaning new 400 kV connections. As the realisation and schedules of the projects are uncertain, it is challenging to make correct and timely investments in the main grid. The final size of a project significantly affects the connection solution, so this uncertainty is a further challenge for main grid planning. Fingrid works with operators in the early phases to consider the appropriate connection needs and solutions.

Offshore wind power also calls for more system engineering studies, which are likely to lead to updated technical requirements. Offshore wind farms located further away in the open sea – more than 50 kilometres from the coast – will probably be connected to the power system by high-voltage direct current (HVDC) transmission links, or the output will be converted directly into hydrogen. Fingrid's technical requirements for HVDC connections must be updated to consider offshore wind power connections. System security studies will also be needed. For example, it is necessary to determine the highest permitted connection power and examine system engineering phenomena to control factors such as stability phenomena.

Solar power

The solar power production capacity in Finland has increased rapidly in recent years. At the end of 2021, the installed capacity was 395 MW, according to the Energy Authority[4]. The figures for 2022 have not yet been received. Most solar power production is from fairly small building-specific installations, but industrial-scale solar farms will play a larger role in the future.

Fingrid expects the volume of solar power to continue increasing sharply, reaching 6–8 GW by 2030 (Fingrid 27). Although the corresponding annual output is only 5–8% of Finland's electricity consumption, 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. In 2023, there were solar power enquiries for more than 60,000 MW of output. The largest projects planned have capacities of up to 1,000 megawatts.

Solar power production capacity and electricity production

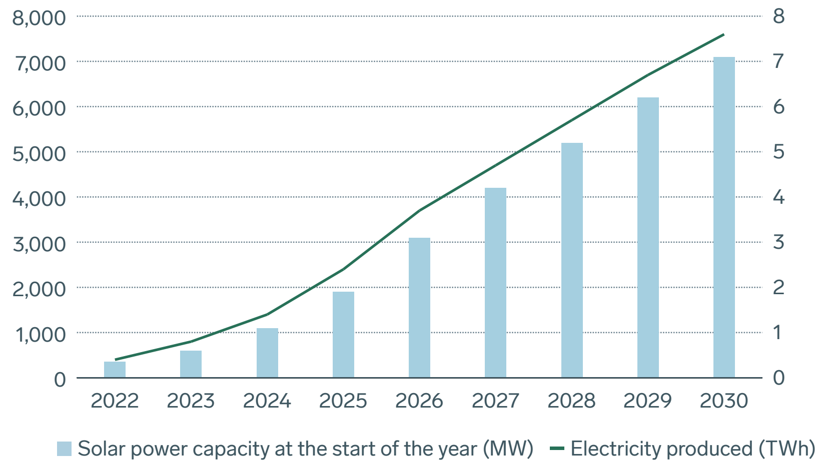

Figure 27. Solar power growth scenario.

[4] energiavirasto.fi/-/aurinkosahkon-kapasiteetti-kasvoi-suomessa-yli-100-megawattia-vuonna-2021

Nuclear power

Finland's nuclear power output has typically been 22–23 TWh per year, covering about one-third of total electricity production. Olkiluoto 3 will raise the production of nuclear power to 35–36 TWh per year. In February 2023, the Government granted new operating permits for both units of the Loviisa nuclear power plant until 2050. Therefore, nuclear power production will remain steady throughout the period examined by the development plan. Small-scale modular nuclear power plants are not expected to gain a foothold in electricity production this decade.

Other forms of production

Hydro power is an important stabiliser in the electricity system due to its adjustable output, significant capacity for energy storage and renewable nature. No significant changes in hydroelectric power production are expected during the review period.

The annual volume of electricity generated at combined heat and power (CHP) plants has typically been in the range of 20–22 TWh, except in 2020, which saw the onset of the coronavirus crisis and strikes in the forestry industry. Consequently, total production was less than 18 TWh. There was also a substantial downward deviation in generation in 2022 when CHP generation fell to around 16 TWh due to prolonged industrial action at UPM and fuel supply problems caused by Russia's invasion of Ukraine.

The phasing out of fossil fuels, especially coal, will reduce the combined heat and power capacity and production in the future. The combined heat and power 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. A substantial amount of capacity has been closed or dismantled. 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.

Prospects for electricity storage and demand-side management

Electricity production and consumption in the electricity system must be in balance at all times, which means that as electricity production becomes less adjustable, electricity consumption must correspondingly become more adjustable. As the amount of renewable, weather-dependent electricity production increases, there will be a greater need for demand-side management and electricity storage or the storage of heat and energy produced with electricity as a result of sector integration. There is significant potential for demand-side management, and a large proportion of that potential is expected to be put to use in the electricity system. Storage facilities make it possible to accumulate electricity when it is available in large volumes at low prices and use it when supply is limited and the price is high.

Industrial electricity consumption may be partly flexible, depending on the production process, and the intermediate storage of products also creates opportunities for flexibility. For example, when the electricity price is high, consumption can be reduced in industry. In addition to industry, households and the service sector make up two-thirds of peak power demand.

Smart electricity consumption 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. This also minimises costs and the need for manual control. Consumers – whether they are industrial or household consumers – benefit from flexibility in the form of lower prices. If necessary, control can be handled by an aggregator, which coordinates flexibility from various sources and can make it available to the electricity market or network operators (known as a "virtual power plant").

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 the demand for flexibility and causes power adequacy challenges. Indeed, it is important for electric vehicle charging infrastructure to be implemented smartly from the outset. This is also the assumption in Fingrid's system plan. The possibility of feeding electricity from vehicle batteries to the electricity grid (Vehicle-to-Grid or V2G) may become important for balancing the electricity system.

Electricity storage technologies include batteries and pumped storage power stations. In the battery field, developments are underway in large battery power plants connected directly to the main grid and decentralised batteries built for distribution networks or directly for end users. Several battery power plants are already operating in Finland, and many more are under development. In addition, Finland's first pumped storage power plant is planned for construction in Pyhäsalmi.

Heat produced using electricity is already being stored in hot-water tanks in buildings and in large-scale heat accumulators in district heating networks. The heat accumulators operating today rely either on direct storage of hot district heating water in a large tank or on the principle of binding heat in a large mass of sand. Heat accumulator projects are planned – especially large-scale ones – to offer flexibility to the district heating system for several hours or, in the best cases, for entire seasons.

As the consumption of Power-to-X processes increases, the storage of the related hydrogen, fuels or other intermediate and finished products will become more important for flexibility in the power system. These types of storage also enable better use of renewable green electricity, such as the production of electric fuels, which will also increase the value of the finished products. There are still uncertainties surrounding the process storage technologies and methods.

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 most competitive technologies will ultimately be selected for each purpose. Overall, the volume of storage facilities is expected to increase significantly.

The batteries of electric vehicles represent a potential energy storage solution.

Main grid customers now and in the future

The number of electricity-intensive projects planned in the 2020s has increased significantly. An electricity grid connection is a prerequisite for the implementation of these projects, and Fingrid works closely with industrial operators from the first steps onwards.

The largest electricity-intensive projects are hydrogen-based steelworks, electrolysis plants producing hydrogen, and heat production in cities and industries. The electricity consumption of the individual sites various from tens to up to one thousand megawatts. Electricity consumers of this scale are unprecedented in Finland.

In urban areas, the production of electricity and heat based on combustion is on the decline, to be replaced mainly by heat pumps and boilers. Heat storage enables heat to be produced at windy times and at night when cheap electricity is available on the electricity market. The technology required to produce hydrogen is still in the early stages of development. For now, electrolysis plants are expensive, and many operators plan to run their processes continuously, even when no cheap electricity is available. As the technology develops, further effort will be required to ensure demand-side management so that consumption more closely tracks the output of weather-dependent electricity production and the electricity market price. Flexibility will also enable smaller industrial grid connections and, therefore, more efficient use of the existing infrastructure. Ideally, electricity production and consumption facilities should be located close to each other, so less of the electricity transmission grid is required between production and consumption.

In recent years, electricity producers and network operators have worked more closely together on the design of electricity networks and grid connections. It is important for society that the electricity grid infrastructure is used as efficiently as possible so that the costs and, especially, the environmental impacts are minimised. In many places, production connections are planned with a 400+110 kV transmission line structure so that one line can transmit the electricity produced by several wind and solar power plants to the main grid. In addition, the 400 kV connection networks in many locations are planned so that they can later be upgraded into ring networks and taken into use by the main grid.

Fingrid offers operators 400 kV transmission line design documents so that different parties can build high-quality, cost-effective transmission lines that are compatible with the main grid. In addition, connection network companies are being developed to offer connection network services to various operators. The outcomes are a cheaper grid connection for producers and lower environmental impacts, as several power plants can be connected to the grid by individual connection lines. Grid connections are also used more efficiently by hybrid parks that contain wind and solar power plants in the same area. The aim is for separate solar power projects to be located further south in Finland and far from wind power projects so that there is enough grid connection capacity for both forms of production.

When wind and solar power are concentrated in certain geographical areas, the main grid connection capacity will inevitably run out in the area, despite the fast pace of grid construction. The shortfall will only be remedied when the necessary grid reinforcements can be built. This has already occurred on the west coast. In a few locations, a solar power project granted a permit in under a year has overtaken a wind power project, as the process for obtaining a permit for a wind power project takes considerably longer. Fingrid is conducting a study to identify ways to maximise the main grid connection capacity when connecting wind and solar power to the same section of the grid.

The website of the Confederation of Finnish Industries contains information on public green transition investment projects. The Finnish Wind Power Association also publishes information on wind power projects. The wind and solar power projects in the permit-application, construction and operating phases are also shown on Fingrid's Verkkokiikari map service, which also shows the transmission line and substation pro-

jects in Fingrid's investment plan and the available connection capacity at each connection point in the main grid. In practice, the connection capacity cannot be stated exactly, so customers are advised to submit connection enquiries on Fingrid's website at the early stages of a project or consumption project. Connection enquiries are free of charge, and Fingrid keeps them confidential. The customer receives information about connection points, the connection capacity status, future network reinforcements, and a preliminary connection schedule.

In recent years, Fingrid has received connection enquiries for more than 80,000 MW of electricity production every year. In addition, electricity consumption connection enquiries have been received for more than today's total electricity consumption in Finland. It is good to obtain information about potential connection projects at the earliest possible stage, as the grid plans made today will come to fruition many years from now, and the service life of the grid varies from 40 to 80 years.

A functioning main grid and distribution networks are absolute competitive advantages for Finland in the international competition for large production and consumption projects. The processes involving operators' grid connection permits and construction also take time, so it is important to speed them up. Fingrid seeks to offer its specialist expertise and support to new operators when they implement grid connections. Industrial operators' requirements for grid connection capacity and transmission reliability often evolve over time. The existing grid capacity is often sufficient to enable operations to start up, and the power can be increased as potential grid investments are completed. In addition, it is often possible to offer high connection powers quickly if the operator is prepared to compromise on the system security or disturbance tolerance of the grid connection temporarily.

New industries will connect to distribution networks as well as the main grid. In several cities, Fingrid is planning solutions to develop electricity networks in collaboration with distribution system operators and other stakeholders. The increase in electricity consumption and the growing need to improve the transmission reliability in distribution networks are giving rise to new investment needs in the main grid.

Fingrid will invest a record sum in the main grid over the next 10 years. New electricity production and consumption customers will share the growing costs, so Fingrid's grid service fees will remain low.

Balancing weather-dependent production

As renewable and variable production and new electricity storage and demand facilities, such as electric transport and smart energy management in buildings, become more widespread, the fluctuations of electricity consumption and production in the electricity 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 production and consumption will have a greater effect on the need for electricity transmission, which will vary more significantly on a local, regional, and national level.

Thanks to the integration of wind power alone, peak transmission demand in the main grid is likely to coincide with very strong winds, both nationally and regionally. 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 production, consumption, and storage to keep the transmissions within the limits of the network's capacity. During these hours, there is a surplus of electricity, reducing the disadvantage of local flexibility.

New technological solutions for consumption, production, and storage in the power system and the opportunities presented by sector integration will facilitate the management of the system in the future. 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 price flexibility in the balancing power and reserve markets.

Fingrid's OneNet research and development project, which began in late 2020, is examining the prerequisites for utilising market-based flexibility in main grid transmission management in cooperation with distribution system operators. The aim of the project is to study the situations in which flexibility could be used for grid management, such as during planned outages. The project will also explore the possibility of connecting energy resources to the grid with "flexible connection agreements" if the grid investments required for the connections have not been completed. The project will also pilot an information system for centrally managing information on flexible resources and optimising the use of flexibility offers from the market between network operators to resolve bottlenecks. The project vision is to enable electricity production, consumption and storage facilities of all sizes to participate in the market and obtain this flexibility for the power system's needs.

Location of electricity production and consumption facilities

In order to enable the conditions conducive for as many electricity production, consumption and storage projects as possible, projects are encouraged to find locations where the power system's capacity is available or can be increased sufficiently quickly and cost-effectively. Alternatively, demand-side management may be a requirement in areas where the grid transmission capacity is scarce. Grid service and connection fees could be adjusted to incentivise investments in certain geographical locations. On the other hand, it is important to note that several factors influence the locations of projects, and the nudging effect of grid service and connection fees may be less significant than other cost factors.

In addition to influencing the geographical location of investments, it is important to ensure the flexibility of production and consumption according to transmission management needs. Even if production and consumption are geographically far apart, situations with the greatest transmission needs are manageable if production and consumption facilities can be flexible whenever necessary. Bottlenecks can be managed by altering the dispatching arrangement after the daily and intraday market, for example, using special regulation. This requires suitable resources to be available at the right points in the network and the necessary flexibility in both directions. Finding sufficient up-regulation capacity – adjustable electricity production capacity or flexible electricity consumption – in Southern Finland is already challenging. It is important to have flexible resources available at short notice, especially in the event of unforeseen faults.

It may be necessary to limit production in advance in certain areas to preserve system security, for example, during a planned outage. Limitations are ordered on the principle of equal and non-discriminatory treatment. One perspective on limitations in circumstances where the full connection capacity cannot be granted to a new network connection in all network operating situations is to explore the possibility of flexible connection contracts. A flexible connection agreement would provide the possibility of limiting the power behind the new grid connection under certain circumstances in which it is not possible to grant access to the full connection capacity. Flexible connection agreements could be a fixed-term solution to bridge the gap until the necessary grid reinforcements are completed. From the point of view of the connecting party, a flexible connection contract enables an earlier connection to the network.

Dividing Finland into different bidding zones is the most dramatic solution for managing production and consumption. Bidding zone division solves the problem, even if the increase in transmission needs has already exceeded the transmission capacity of the network and other means do not help. Based on the simulations carried out in Fingrid's system vision scenarios for 2035, dividing Finland into two bidding zones according to cross-section Central Finland would cause relatively moderate price differences if the transmission capacity were generally sufficient. Similar conclusions were reached in a master's thesis written for Fingrid in 2022 to study the impacts of bidding zone division. The risk of a bidding zone division is that the market is broken down into parts that are too small. This could impact, for example, the liquidity of price-hedging products and the reserve market. However, the current bidding zone division is a rigid solution, and dividing Finland into bidding zones along the north—south axis would not reduce the need for electricity transmissions along the west—east axis, for example. Furthermore, a bidding zone division may not help in all transmission situations, and momentary bottlenecks could still arise regionally. Alongside a bidding zone division, it may be necessary to examine the possibilities of more dynamic models that take better account of the transmission grid's limitations at the time of operation.

As the system grows, the correct incentives for steering electricity production and consumption will enable a sufficient number of investments to support the transmission capacity. This would also not have too large an impact on operators for whom flexibility would be too expensive or complex. Furthermore, if a hydrogen network is built in Finland in addition to the electricity network, it is important that the market guides the use of both infrastructures in an economically optimal way. Hydrogen and electricity systems could work well together and benefit society.

The technical challenges of a converter-dominated system

The challenges for the technical operation of the power system include the increasing volume of wind and solar power connected to the grid via power converters so that these forms of production become the dominant ones and the shift in the consumption structure so that it is increasingly dominated by power converters. The operation of an electricity system is based on maintaining a stable frequency and voltage in all transmission and operating situations. Traditionally, electricity was produced mainly at hydroelectric and thermal power plants using synchronous machines, whose inherent properties resist changes in frequency and voltage. Unlike machines that are physically synchronised to the network, new forms of production and consumption connect to the network via power converters, which do not intrinsically resist frequency and voltage changes. Their response to the electricity system is based on programmed characteristics.

In order to operate, modern-day wind and solar power plants require a sufficiently strong electricity network that maintains the frequency and voltage of the network. As the energy revolution proceeds, the number of converter-connected wind and solar power plants is growing while the number of synchronous machine plants is declining. The increase in converter-connected resources affects a number of different technical characteristics of the electricity system: frequency, voltage, angle and resonance stability, converter-driven stability, electricity quality, and the protection function. Some of the technical characteristics are of a system-level scale (Nordic joint operation, also known as the synchronous area), while others are local phenomena.

The phasing out of synchronous machines will also reduce the inertia in the system. For example, the amount of inertia affects the maximum allowable power change in the system. When inertia is low, it may be necessary to limit the power of the largest electricity production or consumption units. A new type of reserve – the Fast Frequency Reserve (FFR) – has been introduced to remedy this situation. Reducing the system's lowest inertia level increases the rate of frequency change, so solutions other than increasing the amount of fast frequency reserves may also be required to ensure frequency stability.

The transition towards a converter-dominated system has already begun, and the rate of change is accelerating. In 2022, for the first time, converter-connected production momentarily accounted for the majority (more than 50%) of production in the power system of Finland. As the amount of wind and solar power increases, converter-connected production will increasingly account for the majority of production, and the peak share is growing constantly. This is also apparent in the forecasts in Figure 28.

The accompanying phenomena and challenges for the technical operation of the system are new, and there are no established methods for resolving or even identifying all the challenges. However, technical functionality must be ensured in the system of the future. Fingrid works with various experts to understand and resolve the challenges. Cooperation with main grid connecting parties also plays an important role in ensuring that connected installations continue to meet the system requirements in the future. Fingrid is also involved in an ongoing Nordic cooperation project aiming to identify the technical challenges posed by the growth in converter-connected production in the Nordic countries and identify solutions to the challenges affecting the Nordic synchronous area.

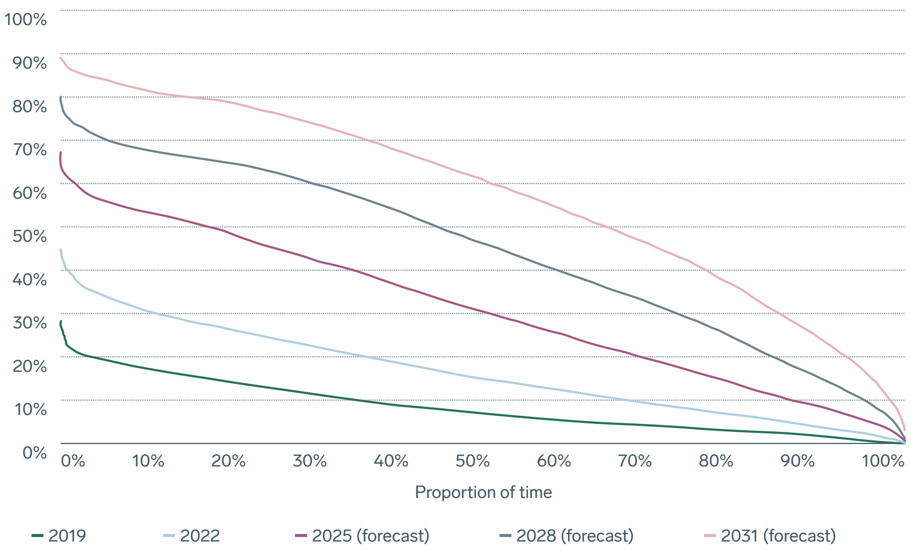

Figure 28. The share of wind and solar power in Finland's total electricity production in all the hours of the year in 2019 and 2022 and the forecast for 2025, 2028 and 2031.

Although the future operating methods – and indeed, some of the challenges – are yet to be identified, solutions are available to address a combination of the requirements on connecting parties, the contract terms, capabilities procured in the market to support the system, and technical network solutions. System security is a common concern for all connecting parties, and connecting parties should also participate in maintaining system security. At present, power converters are required to have some features for supporting network operations similar to synchronous machines, such as fault current supply in a voltage dip and the capability for voltage control. In a converter-dominated system, converter-connected power plants must be able to create network voltage without a reference point produced by synchronous machines. Equipment connecting to the network must comply with Fingrid's grid code specifications for power plants, which will be updated according to the system needs as further insight into the system needs is obtained. Reasonable system requirements may also be imposed on existing connections.

In addition to the requirements for connecting parties, services that support the system can also be purchased in the market. This requires definitions of the new capabilities to be purchased in the market, the marketplaces and the procurement rules. The system's operation can also be supported with a wide range of technical solutions built into the network. In the future, significantly more investments are to be expected in various installations to support the system. For example, a synchronous compensator is under construction in the Jylkkä substation area, where a large amount of wind power is concentrated. The synchronous compensator will stabilise the network voltage and frequency.

06

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 customers, the market 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, the transmission system operators in other countries, the authorities, landowners and other partners, and ensures the availability of services in the sector. It is important for the company's personnel to have an excellent grasp of the 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 Fingrid's stakeholders, 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.

Principles of main grid development

The starting points for main grid development are the future needs of customers and society, promoting the operation of electricity markets in the European and Baltic Sea regions, 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. Main 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 need for development in the electricity market is analysed in cooperation with various market parties. International forecasts and analyses are carried out in collaboration with other transmission system operators.

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 rules 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 grid 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.

The main grid is developed over the long term in a way that benefits the national economy overall 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 shall 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 main grid development and maintenance management are available on Fingrid's website.

Main grid 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). 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 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. The group engages in main grid planning. In addition, at the start of 2021, it 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 Sea region 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 in matters related to the synchronous area. Together with transmission system operators in the neighbouring countries of Sweden, Norway and Estonia, Fingrid is also performing bilateral studies on topics such as the capacity needs and the location and technology for new transmission 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 into account the change in congestion revenues collected by the TSOs. The 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. On the other hand, the investment costs, operating and maintenance costs, and environmental impacts are considered. The impact of system transmission losses – which may increase or decrease as a consequence of the investment – is also considered. 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. Furthermore, the various electricity market parties have been 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)
- A national specification of the technical system requirements for high-voltage direct current (HVDC)

connections and 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 supplemented by instructions that clarify the current requirement base. The VJV, KJV and SJV will be updated in 2023 and take effect by the end of 2024. The general connection conditions were updated in 2021 and, thereafter, they will be updated whenever necessary.

National grid development methods

Main grid planning can be divided into three broad parts: planning of the main transmission grid, planning the development of various regions, and planning connections. In general terms, planning of the main transmission grids means all planning that primarily targets the 400 kV and 220 kV grids. Planning the development of various regions also considers the development needs of the 110 kV network and the adequacy of transformer capacity. Connection planning examines the possible connection points for new projects and the necessary grid reinforcements or other special needs.

At the moment, a lot of large, high-powered connections are planned. For this reason, connectivity assessments require extensive regional plans at many levels, including plans for the main transmission grid. In addition, alternative plans must be made 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 situations.

Vision work

The grid is always planned as a whole in a future-oriented way. In early 2023, Fingrid published its System Vision, which looks ahead to 2035 and 2045, envisioning the development that the main grid will require. The System Vision is a view of the grid's long-term development needs based on various future scenarios that describe the structure of electricity production and consumption. The goal of the System Vision is to present the developments in the main transmission grid that would best serve many different future situations.

Currently, the future scenarios are most affected 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. In order to manage uncertainties in the future, the System 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 us in the future.
Fingrid updates its System Vision every few years. In 2021, the vision work was opened up to our stakeholders and customers for commenting for the first time. The feedback was used to finesse the scenarios that made it into the vision work. For more information about Fingrid's vision work, see Fingrid's website: Electricity system vision 2023.

Planning of the main transmission grid

The main transmission grid enables the connection of large power plants and production clusters to the main grid and caters for the power transmission needs between countries and regions. The main 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 strive for flexibility, since the grid solutions must also serve the system as well as possible in changing situations in the future. 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 transmission grid include:

- Starting points: requirements set for the main grid and the structure of the existing system.
- Changes in electricity production and consumption: forecast trends in the production and consumption capacity, new investment decisions, scenario work.
- Needs for electricity transmission within the country and over cross-border connections.
- Preparing for faults and outages.
- Studies of the operational performance needs of the system, including power and energy balance analyses and grid analyses.
- Comparison and evaluation of the techno-economic alternatives.

Figure 29 illustrates the planning process, and Figure 30 shows the various phases from design to implementation.

Overall, the lead time for a new transmission line, from planning to the finished transmission line, is 7–10 years for lines within Finland and often longer for cross-border lines. Efforts are made to identify the investments required to address various future development pathways earlier than this. For example, this is one focus of the System Vision and other strategic network planning. Investment needs are typically revised as planning progresses. When planning the main transmission network, it is also important to examine how the system will work as a whole when the structure of production and consumption changes. A further question is whether a different range of network technologies will be needed in the future. Important assessment criteria in main transmission grid planning are:

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

The transmission capacity can be increased by means such as adding new physical connections and investing in series and parallel shunt compensation. In addition to building new lines, the capacity of the main transmission grid can be increased by making various adjustments and using reactive power compensation solutions, as system stability often limits the transmission capacity before the thermal current-carrying capacity of transmission lines has an effect. As new technologies develop, new opportunities have arisen for utilising the full transmission capacity, such as Dynamic Line Rating (DLR), which utilises the real-time current-carrying capacity of transmission lines.

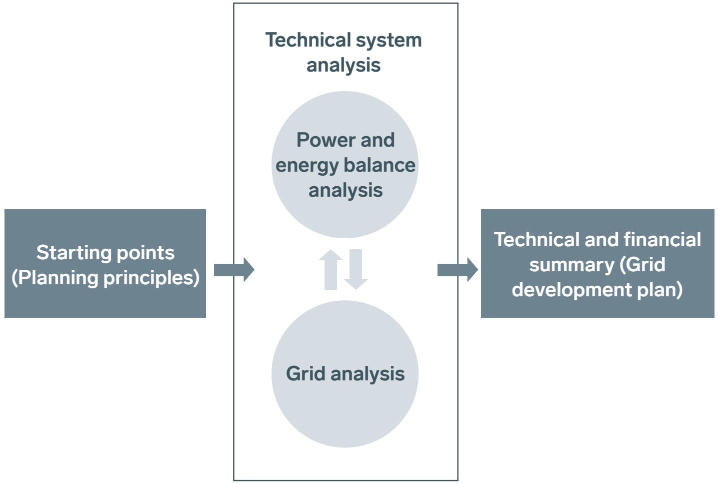

Figure 29. Overview of the planning process.

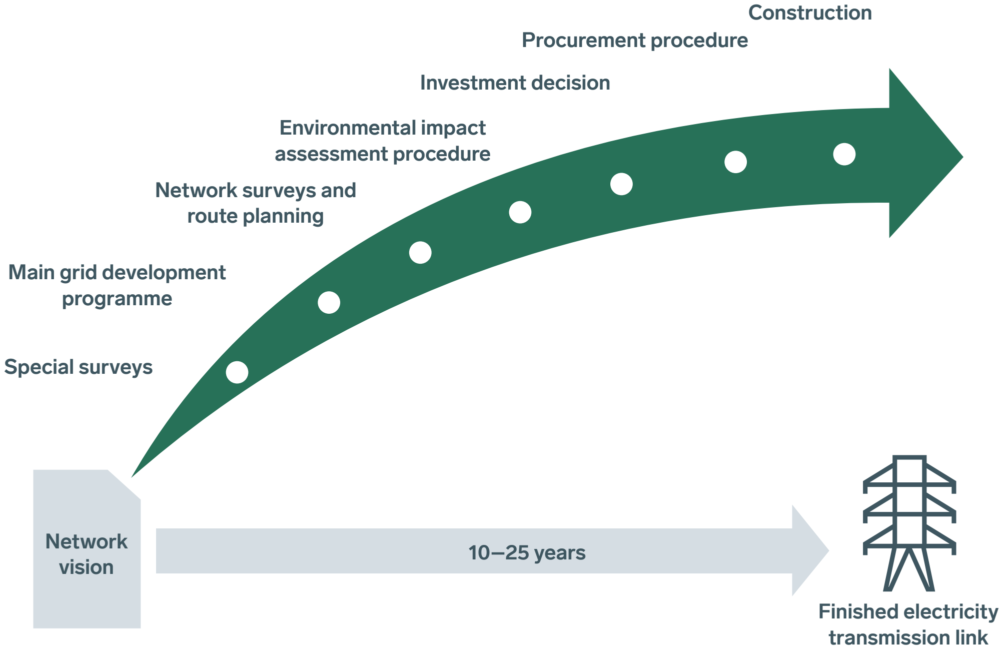

Figure 30. The phases in the main grid investment process, from planning to implementation.

System security is taken into account by the N–1 criterion when dimensioning the meshed 400 kV main power transmission grid. This means making contingencies for the failure of an individual main transmission grid component or power plant so that it does not cause a disturbance.

Grid planning related to the development of various regions

The main grid is divided into four planning areas: north, south, east and west. Planning covers customers' needs, the condition of the grid, the development projects required for system security, and, for example, studies of the adequacy of transformer capacity. 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 planning

The starting points for planning are the dimensioning principles. The 110 kV and 220 kV main grid is dimensioned according to the N-1 principle. This means that the grid must be capable of withstanding a fault in an individual component without the grid becoming overloaded, 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. For example, 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 area. In certain regions, transmissions in the main transmission grid 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, 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 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 production 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 increase, this form of energy has become regionally significant and a planning criterion for dimensioning.

Finland's electricity consumption is traditionally highest during the long, cold winter. However, more transmission capacity is available in the winter as the cold air cools the transmission lines and network components. The heating load in the summer is smaller, but the cooling load is larger. Less condensing and back-pressure production is used in the summer, but it is declining in importance as the total volume of conventional power production in the system decreases. Power plant overhauls are usually carried out in the summer. Consequently, large grid transmissions can also occur during the summer. The thermal transmission capacity of overhead wires presents a particular challenge in the summer, as the warmer weather reduces the capacity. The outdoor temperature has a major impact on the thermal current-carrying capacity of 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 production varies according to the wind strength and can change suddenly. This means that the grid must be dimensioned for the largest and smallest outputs. In Finland, the principle is that neither production nor load is limited in a normal grid situation. As a result, mechanisms to limit wind power production have not yet been used as a grid planning tool, except as a solution for changeover periods when the limit mechanism is temporary.

Hydro power production can vary dramatically, depending on the hydrological situation, the electricity price, and the available reservoir capacity. Industrial back-pressure power is operated according to the related industrial processes. With regard to the ever-decreasing number of 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 exceptional circumstances. Today, it is more difficult to forecast power plant operating patterns because of the recent changes occurring in the electricity market and energy system.

Planning process

Grid planning requires group work in which experts from different areas participate in defining the boundary conditions for planning and brainstorming. Figure 31 presents a simplified diagram of the implementation of the regional development plan for the main grid.

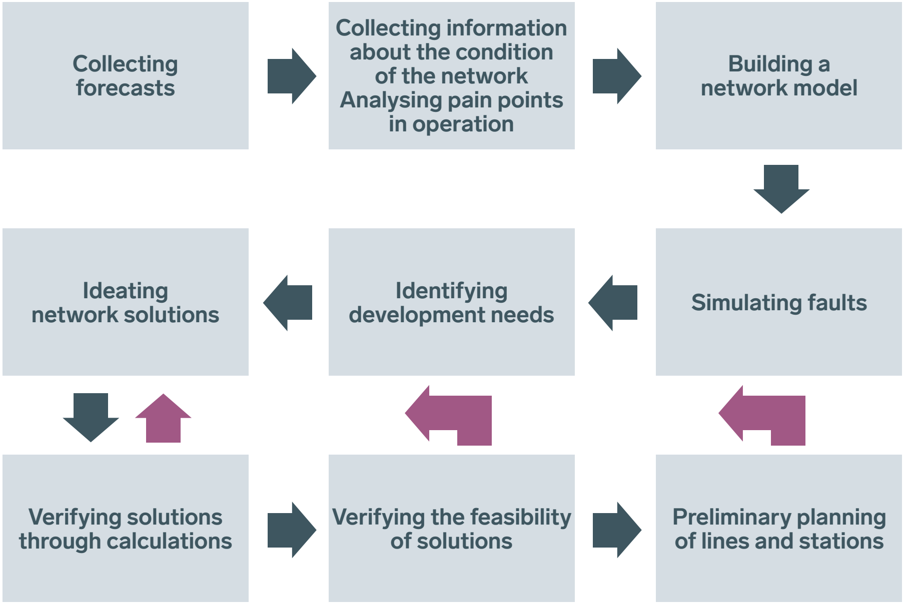

Figure 31. The progress of regional development plans for the main grid.

Planning is based on confidential discussions with electricity producers, large industrial companies and network operators, and customers' views on the electricity grid development needs in the region. A confidential and open dialogue with entities in the sector is essential for grid planning, as sometimes even large industrial facilities can be built more quickly than the required main grid connection and grid reinforcement. In addition to building out the grid, time must be reserved for dealing with environmental and land use issues and obtaining the necessary permits. A further aim of discussions with industry and power producers is to survey the possible changes in capacity and the impacts of improving process efficiency on consumption or production.

Electricity consumption forecasts for regional and distribution networks are influenced by trends in 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 and production. The actual power levels, transmissions and operational methods of power production can be estimated by analysing main grid metering data. Industrial changes can occur at a rapid pace, but investment decisions sometimes take a very long time to happen. As a result, main grid planning must strive for flexible solutions that can cover the transmission needs of electricity consumers and producers without unnecessary investments.

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 main grid planning. The expected electricity consumption and production for each substation and connection point is estimated based on forecasts and measurements and added to the model in the network calculation software. Grid sufficiency can be assessed by simulating various faults and abnormal switching situations. If the grid does not have sufficient transmission capacity, various grid solution ideas are brainstormed and verified by calculations. 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.

A future grid model is used to calculate power flows, generally for 5, 10 and 15 years from the present day. Potential development trends are also assessed over a longer horizon. Grid development needs in the distant future occasionally influence grid planning and construction in the near future. For example, substation location plans and transmission line routes must consider the future situations and requirements.

The land use needs of new substations and transmission lines must be considered when planning. A new plan must be developed if projects are not possible with regard to land use. Grid investments should not be made upfront unless there is a special reason to expedite the timetable. One such reason could be the lack of available transmission outage times. Predicting the future is very difficult, and it is only becoming more challenging as the operating environment changes rapidly. It is easier to make correct investments when the grid plan is implemented as close as possible to the time of need.

The grid plan corresponding to the most probable future situation is added to Fingrid's main grid investment plan. The grid plans and development plan are updated as the operating environment changes and plans are revised. The plans are reviewed with customers during collaboration meetings and grid development webinars.

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 a substation connection and a transmission line connection. A substation connection is a connection to 400, 220, or 110 kV switchgear at a Fingrid substation. Connections with an electrical power of more than 250 MVA are only possible at the 400 kV voltage level. For reasons of system security, connections at the 400 kV or 220 kV voltage levels are always implemented at a Fingrid substation.

Finland's main grid transmission lines are long, with sparse switchgear installations due to the length of the country and its low population density. For this reason, connections to 110 kV transmission lines are also permitted after consideration of the available transmission capacity on the transmission line and other technical constraints. 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. The maximum rated power of a transformer connected to a transmission line connection is 40 MVA, and the lowest permissible short-circuit reactance is 48.0 ohms. If the transmission capacity of the main grid transmission line permits it, up to 65 MVA of transformer capacity can be connected to a single connection point, and the connection can have a maximum load of 60 MW. Within the constraints of the specific requirements, a single 63/31.5/31.5 MVA three-winding transformer may also be used.

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 also 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's general connection terms (YLE), which are a part of the connection agreement, specify the general technical requirements for electrical installations 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, major changes can 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. The investment projects presented in the development plan are a snapshot of the investment plan at one point in time.

07

Starting points for the development plan

Fingrid's main grid and the Finnish electricity transmission system

Fingrid's mission is to secure the electricity supply in our society under all circumstances and to promote a clean, market-based power system. Finland's electricity supply is secured by transmitting electricity through the main grid – the high-voltage network or "highway" of the power system – from production facilities to industrial customers and electricity companies. The nationwide main grid is the backbone of the electricity transmission network, connecting major electricity producers, electricity-intensive industries, and electricity distribution networks. The majority of electricity consumed in Finland is transmitted via the main grid.

Our electricity system is part of the pan-Nordic power system, along with systems in Sweden, Norway and Eastern Denmark. Electricity constantly flows from one country to another. We are also connected to the Central European power system via our neighbouring countries. In addition to its transmission connections to Sweden and Norway, Finland is also connected to Estonia. The cross-border connections ensure a reliable electricity supply even during the highest electricity consumption peaks. Sufficient transmission connections also safeguard a functioning electricity market.

The main grid includes substations and the 400 and 220 kV transmission lines, as well as the most important 110 kV transmission lines in terms of electricity transmission. Under the Electricity Market Act, Fingrid must designate and publish the transmission lines, substations and other installations included in the main grid. Designations are made for each regulatory period applying to the pricing of grid services and submitted at least nine months before the start of the regulatory period. Figure 32 shows Fingrid's electricity transmission network, and Figure 33 shows the network assets in figures.

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.

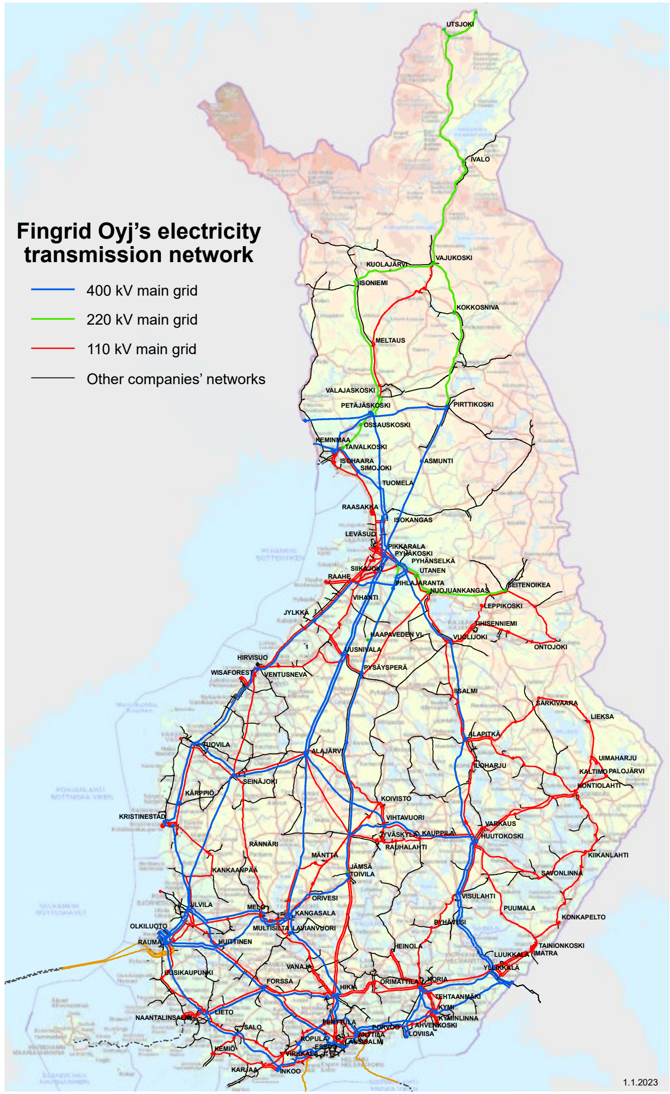

Figure 32. Fingrid Oyj's electricity transmission network.

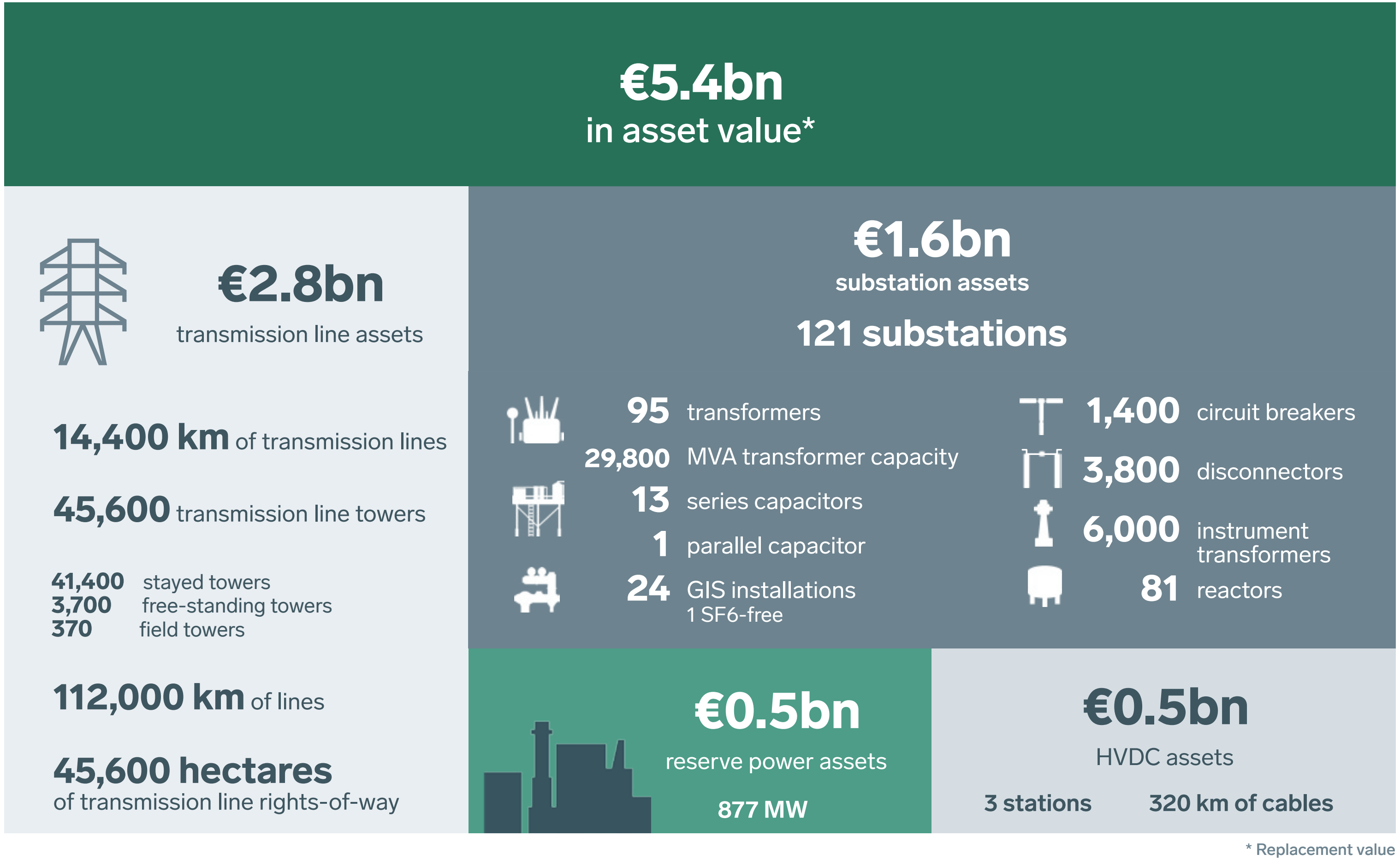

Figure 33. Fingrid's network assets in figures.

Life-cycle management in the main grid

The main grid consists of transmission lines and substations, which in turn comprise many different devices and structural elements. 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 devices and structures 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 for each device separately. 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 expected service lives of transmission line components are between 40 and 80 years; the shortest are for optical ground wires (OPGWs), and the longest are for freestanding steel towers. The expected service lives of substation devices are clearly shorter: between 30 and 60 years. The tables below present the technical service lives of grid components in accordance with the regulatory model.

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

The Finnish main grid has taken its present form over more than 80 years. The oldest 110 kV transmission lines still in use were built in the 1940s. The majority of the main grid's oldest parts have already been refurbished or replaced. However, some ageing 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 31 years, which is more than ten years higher than the average age of the high-voltage devices 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.

Age distribution of Fingrid's towers

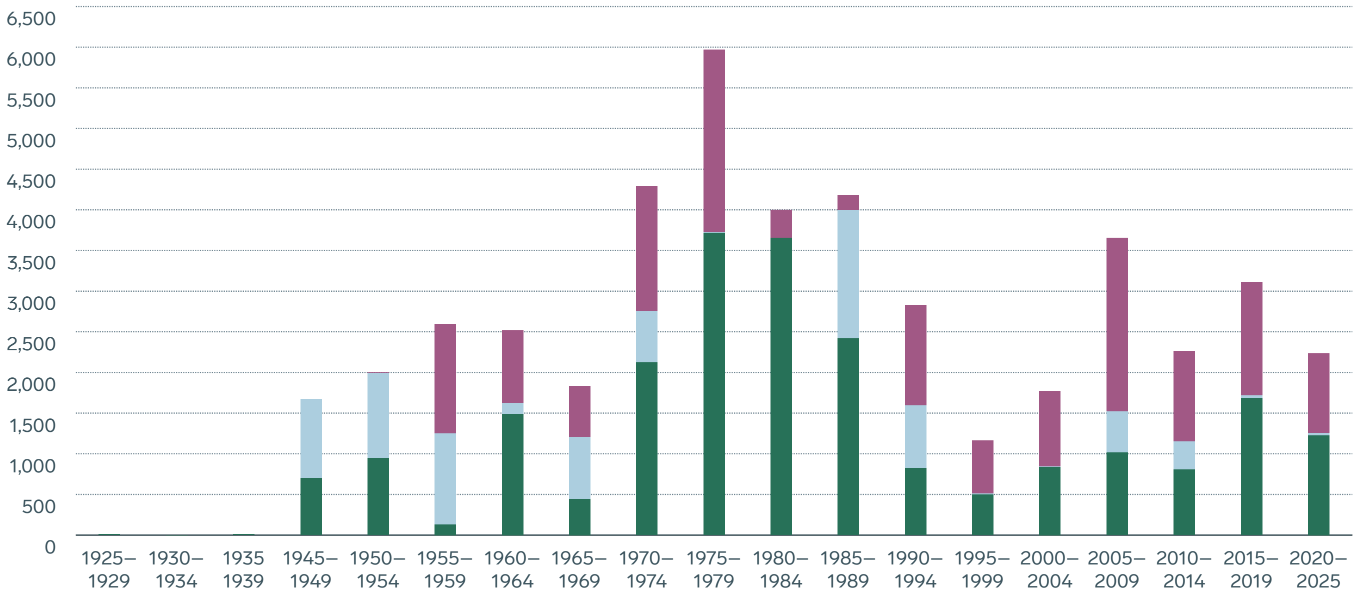

Figure 34. Age distribution of transmission line towers in the main grid.

As a device nears the end of its lifetime, efforts are made to time its replacement before damage and an increasing number of faults cause problems. The timing is influenced by the condition of the equipment and factors such as the availability of operational outages and suitable replacements. The life cycle can be extended by repairing and refurbishing equipment. Sometimes, replacement investments can be delayed deliberately. This enables the most rapidly ageing parts to last until a suitable replacement date. A minor deterioration of system security due to the postponement is permissible, but there can be no compromise on operational and personal safety.

Despite maintenance, not all grid devices reach the end of their normal service lives. Sometimes, poor individual components or device types must be replaced sooner. Devices damaged by external factors or faults must be replaced immediately.

Network components with insufficient current-carrying capacity are replaced by a stronger network. An old device can also be replaced with a new one if the new device has superior technical features or lower losses. A device or grid component that becomes unnecessary can be moved to a new location or decommissioned. Early replacement investments can also be made for safety and environmental reasons.

A comprehensive and up-to-date asset management system containing historical data on the devices is an important tool for optimising service lives. 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 network operators. Among other things, cooperation provides experience-based information about device usage and faults – information that would otherwise accumulate slowly.

The aim is to keep the main grid's system security at a good level despite ageing. The timing decisions related to the refurbishment, repair 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. The main grid maintenance and refurbishment needs identified through condition inspections and in other manners are collated 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. An important aspect of maintaining the main grid investment plan is close cooperation between maintenance management and grid planning.

New condition management technologies

New digital condition management solutions can be used in novel ways to anticipate the onset of faults and, for example, identify frost loads. This improves the visibility of the condition of devices 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. Digital condition management seeks to enhance visibility, especially of the condition of substation equipment, thereby improving system security and risk management. Digital condition management helps to shift operations from a time-based approach towards a needs-based one. Condition management solutions have been developed successfully by means such as innovation competitions with supplier partners.

The first versions of the digital condition management systems were deployed in 2021 and 2022 and can be used to monitor the condition of switching devices and current transformers. The deployment of monitoring systems for these primary substation devices will continue in the coming years. Fingrid aims for such systems to be widely used to monitor main grid assets by 2025. The digital monitoring system platform also enables more efficient use of the existing monitoring solutions and the development of new monitoring solutions to support maintenance activities. Fingrid will continue to study possibilities for cooperation with other applicable transmission system operators to promote the development of digital condition management.

Alongside traditional on-site visual condition inspections, unmanned aerial vehicles (drones) are increasingly used for network condition inspections. Drones can take detailed close-up pictures in applications such as special inspections of tall tower structures and aerial photographs of substation equipment that is difficult to observe from ground level. In the future, automatic image recognition could be used with large image datasets to identify sites with clear maintenance needs. Drones are also used for quality assurance in maintenance work, especially in difficult terrain.

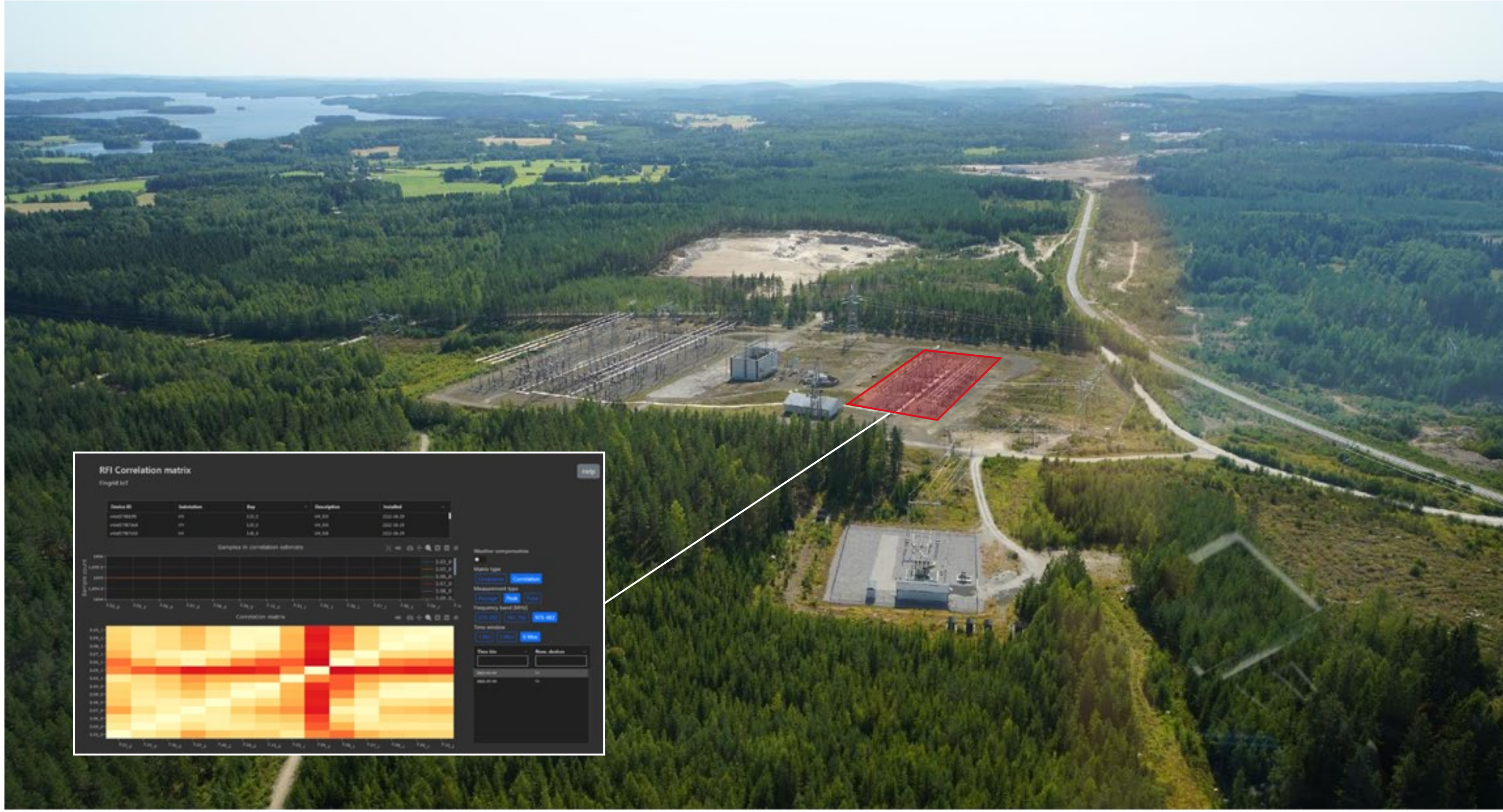

Figure 35. Digital condition management systems can detect deviations in substation equipment. Pictured: the Vihtavuori substation in Laukaa.

Corporate responsibility and environmental awareness

Fingrid is committed to responsible and ethical operating practices to promote sustainable development in its vital duty to society. Fingrid realises its climate and environmental responsibility, social responsibility, and corporate governance in line with its Environment, Social and Governance (ESG) model. In particular, Fingrid's business promotes the UN's Global Sustainable Development Goals (SDGs) related to climate action, energy, and infrastructure.

Fingrid's business generates substantial common value for its customers, personnel, contractual partners, owners and Finnish society. Everyone in Finland can appreciate Fingrid's mission and the value of an adequate, reliable electricity infrastructure in the form of a reliable electricity supply, which is by no means self-evident everywhere in the world. Societal value is reflected in Finland's competitiveness, as the company facilitates investments in Finland while charging low grid service fees relative to the reference countries. The dividends paid to Fingrid's Finnish owners and the taxes paid to society contribute to the well-being of Finnish society. Value is created for Fingrid's personnel and the service providers employed in numerous projects. Value is also created for the achievement of climate goals by building the strong main grid and functioning electricity market required for clean electricity. Fingrid publishes detailed corporate responsibility reports on its website and in its annual report.

Value created by Fingrid in 2022

VALUE CREATION

- Fingrid’s national main grid is the basis for a clean electricity system. Approximately 500 kilometres of new main grid transmission lines and 16 new or expanded substations.
- Security of the energy supply: 99.99993%.
- A total of 1,940 megawatts of wind power was connected to the main grid, which will lead to an annual indirect reduction of 357,000 tonnes of CO2-equivalent emissions. Reliability of cross-border connections: 98.6%.
- Among Europe’s most cost-effective electricity markets in a comparison of supervisory authorities. Second-lowest pricing in ENTSO-E’s comparison of European price levels. Customers feel that Fingrid works in the interests of society (4.4/5).
- The personnel feel that their jobs are meaningful, and they are willing to recommend their employer (eNPS 72). Lost-time injury frequency: 5.4. Absences due to illness: 1.5%. Training: average of 5 days/employee.
- One of Finland’s largest corporate taxpayers (EUR 47m). Compensation to financiers and shareholders: EUR 150m.
- Investments in the main grid: approx. EUR 250m. Person work-years by Fingrid employees: 447 and by service providers: 642.
- Total direct carbon dioxide emissions and indirect carbon dioxide emissions due to electricity consumption and losses: 106,000 tonnes of CO2-equivalent emissions (scope 1 and 2). 99% of waste utilised and 82% recycled.

Fingrid contributes to these UN Sustainable Development Goals

01 RESOURCES | 02 BUSINESS PROCESS | 03 IMPACTS | 04 VALUE CREATION

Figure 36. Value created by Fingrid in 2022.

Fingrid's main environmental perspectives

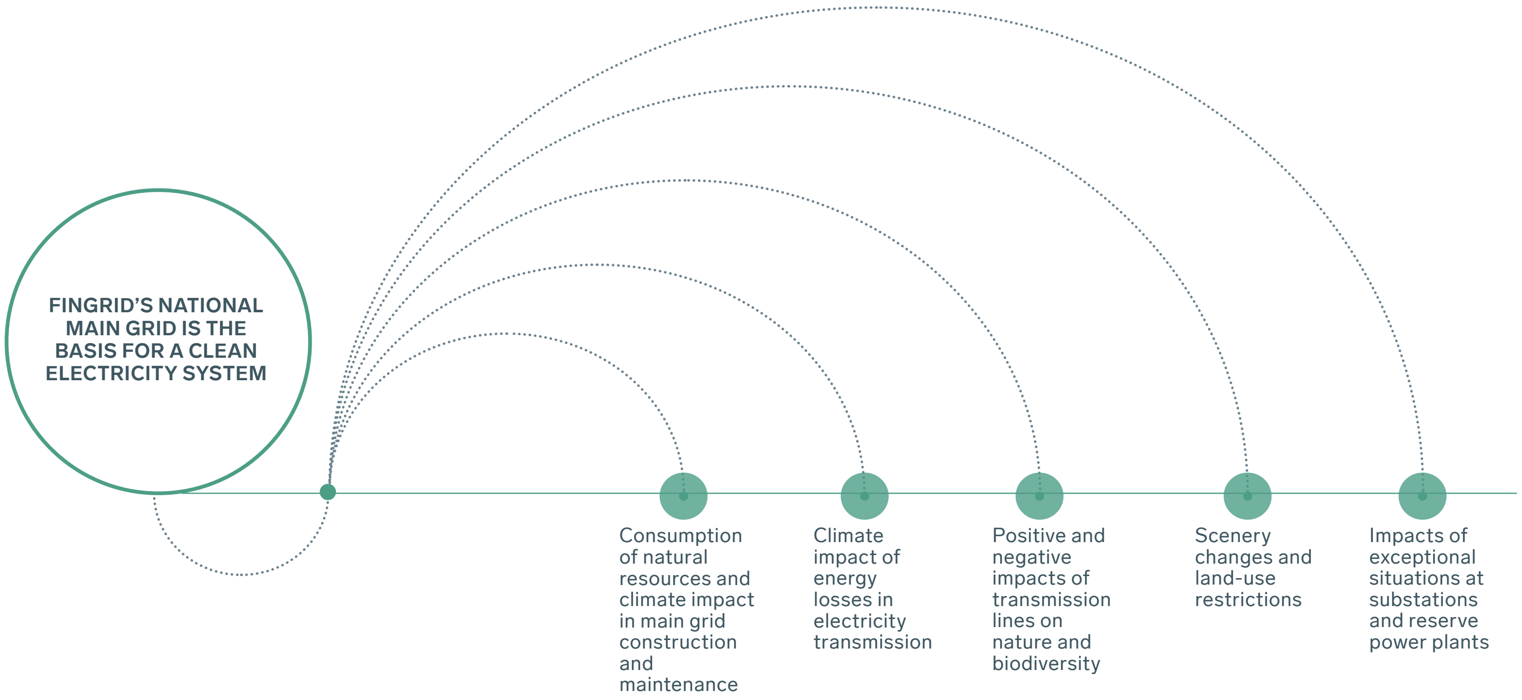

Figure 37. Fingrid's main environmental perspectives.

Taking landowners into account, transmission line planning and permit applications

Interaction with landowners in transmission line rights-of-way and residents living near main grid transmission lines is important to Fingrid. Communication begins when Fingrid plans the preliminary transmission line routes, assesses the environmental impacts and studies potential ways to mitigate them. Fingrid maintains active communication with landowners and continuously improves its operating methods based on feedback.

The prevention and mitigation of harmful environmental impacts in a transmission line project begins with route planning. In accordance with the nationwide land use objectives stipulated in the Land Use and Building Act, existing transmission line routes are primarily used for route planning. When transmission line routes are planned in entirely new terrain, Fingrid seeks solutions to avoid building in the immediate vicinity of settlements and valuable natural and other environmental sites. Route options are planned at the base map level, taking into account the spatial datasets produced by the administrative branch of the Ministry of the Environment. The area's land use plans and other projects are also considered.

In major 400-kilovolt transmission line projects, the impacts on nature and possibilities for mitigation are studied as part of the statutory Environmental Impact Assessment (EIA) procedure. The EIA procedure ensures that landowners and other stakeholders have access to information and can influence the project. An inclusive approach is important for reconciling the transmission line with its environment while taking into account different viewpoints and stakeholders. As part of its EIA procedures, Fingrid has continued to provide local residents with more extensive information than required under the statutory practices.

Fingrid sends landowner letters and, if necessary, publishes information in local newspapers to supplement communications from the authorities.

Transmission line routes are revised during site visits and the EIA procedure, when Fingrid identifies and assesses the environmental impacts in more detail. When the EIA report is completed and the coordinating authority has issued a reasoned conclusion on it, Fingrid selects the final route based on the environmental impacts, feedback and techno-economic principles.

An environmental study is carried out for 110-kilovolt projects with smaller impacts. The information produced by such studies helps mitigate the impacts and preserve the value of sites in further planning and construction. The final route is planned based on terrain surveys in the general planning phase, which follows the EIA procedure or environmental study. Planning utilises remote sensing data (aerial photography and laser scanning). If necessary, the data is verified by visiting sites where lines cross other lines, roads or buildings. The data is used to plan the locations of transmission line towers and conduct the necessary soil surveys at the tower sites to determine the foundation conditions. Landowners are informed of the planning solutions on their properties. In most projects, efforts are made to reach an agreement with landowners during the general planning phase concerning the location of the transmission line on their property.

When general planning is completed, Fingrid applies for an expropriation permit from the Government or, in smaller projects, the National Land Survey of Finland to establish its right of use and, correspondingly, to restrict the landowner's right of use in the transmission line area. Establishing the right of use means that Fingrid gains a permanent right to build, maintain and modernise the transmission line.

When the expropriation permit is granted, an expropriation procedure is initiated with the National Land Survey of Finland. The procedure is carried out by an independent expropriation committee. A preliminary seizure decision is made at the expropriation committee's kick-off meeting, after which transmission line construction can begin. The restrictions required to limit the right of use in the transmission line area and grant the rights to build, operate and maintain the line are brought into force based on the decisions made during the expropriation procedure, and the landowner is awarded compensation for financial losses. In forests, expropriation of a permanent right of use means that compensation is due for forestry losses in the same way as compensation for the redemption of ownership. The landowner retains ownership of the ground and vegetation.

Compensation payable for construction

Section 15 of the Constitution of Finland protects everyone's property. The expropriation of property for the public good in return for full compensation is regulated by law. The Act on the Redemption of Immoveable Property and Special Rights (603/1977) applies to main grid transmission line projects. Based on the Act, the owner of the expropriated property must receive full compensation for the financial losses caused by the project. Compensation is awarded according to the fair value of the property. If it does not correspond to the landowner's full losses, the estimate is based on the asset's yield or sunk costs.

The compensation for expropriation consists of compensation for the object, harm and damages:

- Compensation for the object is awarded for the ground in the transmission line area, tower bases and, in special cases, vegetation and buildings.
- Compensation for harm is awarded for the harm caused by towers and access to the site and the fragmentation of parcels of land.
- Compensation for damages is awarded for premature felling, loss of seedling stand, windfall and loss of crops.

Main grid safety

The structure of the main grid fulfils the electrical safety requirements and distances. Occupational health and safety are the priority for all of Fingrid's activities. It is important to the company that all Fingrid's personnel and the employees of service providers working on Fingrid's sites get home safe and healthy. Alongside occupational safety, it is important for Fingrid that the main grid does not pose a hazard to people or the functioning of the power system.

Comprehensive and proactive maintenance ensures the safety of transmission lines. Transmission line structures and rights-of-way are regularly inspected. The undergrowth is regularly cleared in transmission line areas. The tops of tall trees in the bordering forest areas are cut to a safe height using helicopter saws and felling so that the trees cannot fall onto transmission lines. All faults identified during inspections are rectified proactively before they cause electricity transmission outages or hazards near the transmission line. Inspections were conducted on approximately 5,100 kilometres of lines in 2022. Approximately 5,000 hectares of transmission line corridors were cleared, and around 111,000 cubic metres of timber was felled from bordering forests. Fingrid contacted more than 11,500 landowners in connection with these actions. These measures ensured that the transmission lines remained reliable and, above all, safe in their environments.

Instructions are issued regularly concerning work and other activities near the electricity grid. Fingrid actively participates in land use planning with municipalities and regional councils to ensure safety and land use reservations for the main grid. Electric and magnetic fields worry people in the vicinity of transmission lines. Electric and magnetic fields occur everywhere, and transmission lines are one source of such fields. The limit values for public exposure specified by the Ministry of Social Affairs and Health are not surpassed near transmission lines. In 2023, Fingrid will continue to work with an external expert to publish overviews of medical-focused research from around the world on electric and magnetic fields. No new evidence has been found that differs from previous information.

Technical choices for the electricity transmission system

The following sections present the basic technological solutions that Fingrid uses. They also review a few relevant technologies that are considered beneficial in the changing operating environment.

Basic solutions in the main grid

Basic electricity transmission technology solutions have remained unchanged for decades, and there are no technologies on the horizon that would alter the principles. 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. Finland's main grid is based on overhead wires 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 Fingrid's 400/220 kV and 400/110 kV transformers is typically 400 MVA, and that of 220/110 kV transformers is 100–250 MVA. The transmission lines now being built can be expected to be in use for at least 60–80 years.

The Baltic Sea cross-border connections from Finland to Sweden use direct current technology, which enables the construction of long cable links. However, the drawbacks of HVDC transmission links are very high construction costs and lower system security resulting from more complicated technology. 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.

Basic substation structures:

Substations enable electricity producers and large individual consumers to connect to the main grid. Substations may be transformer substations, which connect transmission lines at different voltage levels, or simply switchgear, which connects transmission lines at the same voltage level. Substations are needed to enable electricity transmission and for switching measures, such as the action needed to limit the impact of a fault. The protective systems in substations detect faults on transmission lines and send automatic disconnection signals to the switching devices in substations. In addition, substations can have compensation devices that increase the electricity transmission capacity of transmission lines and reduce the power losses occurring during transmission.
The basic substation structure is air-insulated switchgear. Indoor gas-insulated switchgear is used on a case-by-case basis. Gas-insulated switchgear is substantially smaller than air-insulated switchgear, so it is suitable for use in urban areas and other sites where space is limited. The basic solutions at the 110 kV voltage level are double-busbar–auxiliary busbar and busbar–auxiliary busbar systems. The basic solutions at the 400 kV voltage level are dual circuit-breaker systems, known as duplex systems, where most of the equipment is duplicated and, for example, a busbar fault cannot cause an outage on the transmission lines connected to the substation. At the 220 kV voltage level, the substation solution is determined on a case-by-case basis. The most common solution in air-insulated switchgear is a double-busbar–auxiliary busbar system.

Basic transmission line structures:

Overhead lines are the basic transmission line solution in the main grid. Underground cables are also used in certain exceptional cases if overhead lines cannot be built due to land use restrictions and the transmission distance is sufficiently short. For example, a new 400 kV underground cable is under construction in the Helsinki metropolitan area. In addition, connections with gas-insulated switchgear are made using short cable sections.

The main grid's transmission lines operate at the 110, 220 and 400 kV voltage levels. The voltage levels affect the tower structure that is used: higher voltages demand larger air gaps and safety distances and, therefore, stronger mechanical resistance.

As a basic solution, Fingrid has developed standard tower types that meet the needs of the main grid. New tower structures are planned as required, and the standard towers are also developed as technical standards and other needs change. Tower structures are developed with the goal of ensuring rapid project planning and consistent quality. The standard tower types make it quicker and easier for new and foreign contractors to plan new transmission lines for Fingrid's needs. The standard structures (towers and foundations) should be used whenever possible.

Transmission line towers are categorised by structure and functionality. The basic solutions used in the main grid are stayed, freestanding and field towers. Figure 38 shows the tower types. Most towers in the main grid are stayed steel towers, where the stays transfer the horizontal forces acting on the structure to the foundations so that only vertical loads act on the tower leg and foundations. All new transmission line towers are made of hot galvanized steel, but a lot of wooden towers are still in use for older 110 kV transmission lines. The legs and arms of stayed towers can be either steel tubes or a lattice structure.

Freestanding towers are used at points where transmission lines turn, as tensioning towers, as two-circuit towers and when the width of the transmission line area is limited. In this tower type, horizontal forces are transferred to the foundations via the frame, exerting significant strain on the tower and the foundations. For this reason, the foundation structure is considerably more robust than for stayed towers. Freestanding towers are almost always made of steel. Field towers, as their name suggests, are towers built in fields. The field tower is a transmission line tower model developed by Fingrid to reduce the adverse effects on agriculture. Today, field towers are used for the 400 kV voltage level and for 400+110 kV joint tower structures. The basic solution for the 110 kV voltage level in field areas is the freestanding tower.

A joint tower structure where several transmission lines are placed on the same tower can be used to reduce the required width of the transmission line area or build a new transmission line in place of an existing one. The most common joint tower structure is a stayed 400 and 110 kV portal tower where the lower-voltage transmission line is installed on an intermediate arm of the tower. The construction of 110 kV joint towers has also increased recently.

Joint tower construction can reduce the land use impacts of new transmission line routes. Tower structures also come with challenges. For example, servicing and maintenance work usually requires both circuits to be unenergised.

So far, efforts have been made to avoid joint tower structures at the 400 kV voltage level. The transmission volumes on double 400 kV lines are large, and the impact on system security in the event of a fault could be significant. Joint tower structures have been used where there is no technical alternative or on sites where they are deemed justified, for example, for significant environmental reasons. Fingrid is studying the potential for increasing the use of 400 kV joint towers to cater for the growing transmission needs of the future.

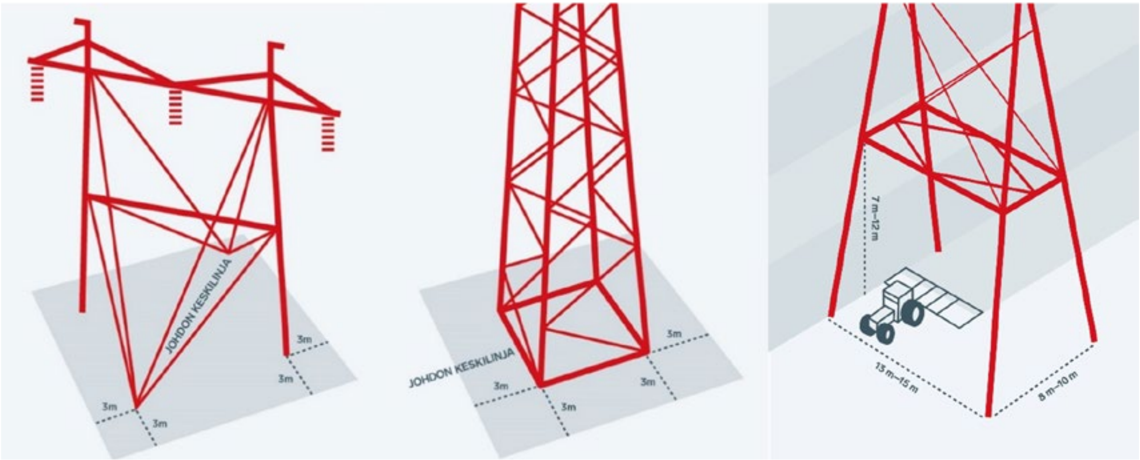

Figure 38. Pictured from left to right: a stayed tower, a freestanding tower and a field tower.

Solutions to boost the transmission capacity and stability of the grid

The transmission capacity of the main grid is limited by the warming of components caused by losses due to resistance. Electricity is transmitted over long distances in Finland, such as from the production plants in Northern Finland to consumption centres in Southern Finland. When electricity is transmitted on long transmission lines, the grid's transmission capacity is often limited by the thermal capacity and technical phenomena in the system. These include the damping of power fluctuations at power plants following a fault and the grid's voltage stability.

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 the damping of power fluctuations at power plants and voltage stability. Series compensation is used on the long 400 kV transmission links between Northern and Southern Finland and between Finland and Sweden.

The main 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 lines 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's selected shunt compensation solution is to build mechanically switchable capacitor batteries distributed over 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 utilised.

In addition to mechanically controlled shunt compensation, a dynamically controlled static VAR compensator (SVC) is used at the Kangasala substation to improve the damping of power fluctuations and voltage stability. Additional stabilising systems at large power plants also make higher transmission capacities possible in the main grid. The world's first wind farm 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.

The latest solution for improving grid stability and connectivity is the synchronous compensator deployed by Fingrid at the Jylkkä substation. In practice, the solution is a large synchronous machine without an energy source. This solution will ensure the reliable operation of wind power production, which is highly centralised on the west coast, and improve the system security of the main grid in the region. A synchronous compensator stabilises the grid's voltage and frequency, allowing wind farm power converters that follow the grid to operate stably under different operating conditions. Fingrid is studying the need to add synchronous compensators or dynamic reactive power compensators (STATCOM) to the substations near other wind and solar power clusters to support the stability of power converters.

Using dynamic current-carrying capacity

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

The traditional way of determining a line's current-carrying 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 current-carrying capacity, as it is necessary to ensure that the transmission line is not subjected to loads above its design temperature under any circumstances. Dynamic Line Rating (DLR) enables the transmission line's actual current-carrying capacity to be used. In practice, the current-carrying capacity of transmission lines in Finland is almost always higher than the value calculated using the SLR method – approximately twice as high on average. The DLR method makes it possible to ensure that the transmission line is not overloaded under conditions in which the actual current-carrying capacity is lower than the SLR capacity. Over the years, several methods have been developed for determining the dynamic current-carrying capacity. DLR is not 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 compatible with wind power because the current-carrying capacity of transmission lines is typically higher at windy times due to the cooling effect of the wind.

DLR calculations usually make use of local weather data, sometimes provided by sensors installed on the line. Measurements of different types may also support the calculations. If measurement sensors are used, the general principle is that the weather data is refined based on the data received from the sensors, and the actual current-carrying capacity of the line is calculated using the standard model (CIGRE/IEEE) based on the weather data.

The dynamic current-carrying capacity of a transmission line 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. The forecasts are calculated using weather forecasts and, in some cases, the previous behaviour of the line, as revealed by measurement sensors.

The DLR method can be used to realise significantly more transmission capacity in situations where the line's current-carrying capacity restricts the transmission capacity. The current-carrying capacity of substation equipment often limits the current-carrying capacity of transmission lines. In such cases, it may be necessary to consider whether the current-carrying capacity of such equipment could be increased to yield additional transmission capacity. Voltage and angular stability can also restrict the transmission capacity.

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Fingrid Oyj
Läkkisepäntie 21, 00620 Helsinki
PO Box 530, 00101 Helsinki, Finland
Tel +358 30 395 5000

Feedback and further information:
viestinta@fingrid.fi

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