Our society is dependent on electricity. Svenska kraftnät is responsible for ensuring that Sweden has a safe, environmentally sound and cost-effective transmission system for electricity – today and in the future. We achieve this in the short term by monitoring the electrical system around the clock, and in the long term by building new power lines to meet tomorrow’s electricity needs.
PREFACE

The board of Svenska kraftnät decided in April 2013 on a long-term plan document for the development of the Swedish National Grid. Long-term plan 2025 described the challenges for Svenska kraftnät in the 10 to 15 years term. The purpose was, among other things, to increase the transparency of Svenska kraftnät’s planning and to provide an opportunity for the various stakeholders in the electricity market to influence it.

Until then, the national network planning mainly consisted of the three-year investment and financing plans that Svenska kraftnät annually provide to the Government. These plans are, however, primarily a description of how investments already decided are expected to turn out over the next three financial years. They do not give an account of the Administration’s long-term priorities and the grounds for them.

A certain network planning is conducted also at Nordic level in order to identify grid reinforcements with specific benefit for the whole of the Nordic electricity market. In addition, new network planning processes have been established at the European level. In the context of the European Network of Transmission System Operators for Electricity (ENTSO-E) a 10-year network development plan – Ten Year Network Development Plan (TYNDP) – is made every other year.

The Swedish National Grid is going through a period of very extensive expansion. The reinforcements are needed to handle additional renewable electricity production, extend market integration with the world around and contribute to the creation of a single European electricity market. In parallel there are very significant reinvestment needs.

In this context a more long-term Swedish network planning is essential. If the long-term objectives have not been identified, there is an increased risk of poor investments in the short term.

On the basis of Perspective plan 2025 [Perspektivplan 2025] the board of Svenska kraftnät today has determined the present ten-year plan, in which Svenska kraftnät’s priorities are amplified and clarified. The plan will form the basis for the company’s further investments and serve as a starting-point for Svenska kraftnät’s contributions to the next European TYNDP. The intention is to update the plan on a biannual basis.

Sundbyberg, 26 November 2015

Mikael Odenberg
Director General
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1. INTRODUCTION

1.1 Background

The community development and the growing dependence on electricity call for a robust and reliable National Grid. High energy-political ambitions to reduce carbon dioxide emissions lead to extensive expansion of renewable electricity production and development towards an integrated European electricity market.

Society’s increased dependence means that tolerance to power failures is reduced, and that prolonged power outages cannot be accepted. It makes increasingly higher demands on the transmission networks of the future. The demands for increased reliability and capacity are driving forces for Svenska kraftnät to significantly increase network investments over the coming years. It is a question about building new plants as well as maintaining and investing in the existing.

Svenska kraftnät’s investments were previously on average at the level of 400 million SEK per year. This investment volume was not a problem for Svenska kraftnät’s planning, recruiting or economy. Now, however, it is evident that the company is in a completely new phase with annual investment levels at SEK four to five thousand million.

The strong growth in investments emphasises the need for the company’s long-term planning for development of the National Grid. Not least, it is important for the electricity market participants and for different groups and functions in society to obtain an insight into Svenska kraftnät’s priority efforts.

The planning work is also pushed forward by the EU’s energy and climate policy with high ambitions for integrating renewable electricity production so as to reduce emissions of climate-affecting greenhouse gases. An important factor for realising these ambitions is the third inner market energy package which, among other things, requires grid operators every other year to develop ten-year plans for the entire European transmission network.

In 2013 Svenska kraftnät presented Perspective Plan 2025, aiming to clarify Svenska kraftnät’s priorities and intentions for development of the National Grid over about 15 years’ time. The basis for the planning work was a market model study that analysed various development scenarios for the production and use of electricity and their consequences for National Grid and investment needs. In the basis of Perspective plan 2025 were also analyses and studies of other necessary investments to create a reliable National Grid with the appropriate capacity.

The Perspective plan explained the projects that Svenska kraftnät deemed necessary to implement until 2025. The plan was, however, not an investment plan with a detailed account of the projects’ costs and timetables.

The purpose of the present document is to be an investment plan for the coming ten years. The investment plan sets out in more detail which projects Svenska kraftnät intends to carry out during the ten year period 2016–2025. The investment plan will also serve as Sweden’s national basis for preparing the next European ten-year plan for network investment1, put forth in the planning work of the European Network of Transmission System Operators for Electricity (ENTSO-E).

It has been two years since the Perspective plan 2025 was presented, but several elements have already changed. It calls for a revision of the perspective plan. These changes are reported in Chapter 3.

1.2 Reading guide

Chapters 2 to 6 show the assumptions that affect the Svenska kraftnät investment plans for the grid. Chapter 2 describes in short form the changes that have occurred since the Perspective plan 2025 was presented. Chapter 3 presents the planning assumptions that Svenska kraftnät has to relate to in its planning of National Grid development. The European climate and energy policy makes an increasing and decisive impact on Svenska kraftnät’s investment plans. It is therefore reviewed in some detail.

Chapter 4 describes the more direct driving forces associated with the grid investments. Chapter 5 presents the challenges associated with the network expansion. These include, among other things, development of electric power system with an increasing amount of renewable production that does not lend itself to planning as does conventional electricity production. Chapter 6 reviews the current electricity system with an outlook towards 2025. It describes the anticipated development that calls for the investments necessary to meet this trend. Chapter 7 constitutes the 10-year implementation plan with descriptions of the projects, broken down by consumer region, which Svenska kraftnät is planning to implement in the next 10 years’ period.

Finally, chapter 8 presents the economic impact of the 10-year implementation plan on Svenska kraftnät and on the development of the National Grid tariff.

1. Ten Year Network Development Plan (TYNDP).
Most of the conditions that went into the Perspective plan 2025 are still at hand. A number of changes have occurred, however, affecting the investments presented in the long-term plan. These changes may also necessitate additional investments. The major changes that are deemed to affect the Svenska kraftnät’s network planning are presented below.

> New capacity mechanisms in Russia have led to exports to Finland largely ceasing. Together with the shut-down of the old condensing power station this has deteriorated Finland’s energy balance.
> The Finnish Parliament has decided to authorise the construction of a new nuclear power station in Pyhäjoki in Northern Finland.
> Oskarshamns kraftgrupp (OKG) decided in October 2015 on an early closure of the two oldest reactors at the Oskarshamn nuclear power plant. Oskarshamn reactor 2 (O2) has been out of service for extensive upgrade work since 2013. The decision means that operation of the O2 will not be resumed. The impact of the decision for Oskarshamn 1 is that the reactor is likely to be finally shut down sometime during the period 2017-2019. The closures will mean a loss of approximately 1,100 MW electricity generation in southern SE3.
> In October 2015 Ringhals AB decided on the early closure of the two oldest reactors at the Ringhals nuclear power plant; Ringhals 2 to be taken out of service in 2019 and Ringhals 1 in 2020. This removes another 1,750 MW of electricity in southern SE3.
> Additional taxes on nuclear power generation of electricity have led to Forsmarks kraftgrupp (FKA) cancelling plans for increasing the effect of Forsmark 3.
> The development in the Stockholm area have prompted a review of time plans for the project Stockholms Ström and resulted in the need for additional lines in the western part of the region, the project Greater Stockholm West.
> New network studies have shown that the 400 kV line from Ekhyddan to Barkeryd does not have to be built. The line is not needed if the line from Ekhyddan to Hemsjö is built.
> The project for a western branch in SydVästlänken between Barkeryd and Oslo area has been ciscancelled on Norwegian initiative.
> Svenska kraftnät has refused to build a new 400 kV connection to Denmark across the sound.
> Svenska kraftnät has developed and detailed the analyses of the future reinvestment requirements in the National Grid.
> The connections Skagerrak 4 and Estlink 2 have been made operative.
> Statnett has decided to build a 1,400 MW HVDC connection between Norway and Germany, NordLink, with operation starting in 2020.
> Statnett has decided to build a 1,400 MW HVDC connection, North Sea Link, between Norway and the UK with operations starting 2021.
> Vattenfall, Agder Energi, E-CO and Lyse are planning to build a 1,400 MW HVDC connection, NorthConnect, between Norway and Scotland.
> Preliminary cost-benefit analyses have been done for Hansa Power Bridge, a new connection between Sweden and Eastern Germany.
> The Government has announced an increased level of ambition for the Swedish-Norwegian electricity certificate system.
> The Government has announced a special support for off-shore wind power.
> The EU Heads of States and Governments have agreed on a new climate and energy policy framework until 2030 which includes new targets for emissions reduction, share of renewable energy, and energy efficiency improvement.
3. PLANNING ASSUMPTIONS

3.1 The EU climate and energy policy

The EU energy policy is based on the three pillars of competitiveness, environmental sustainability, and reliability of supply. This was stated in the European Council’s decision on an integrated climate and energy policy and energy action plan for the years 2007 to 2011. With common objectives on climate and energy, EU wants to show its determination to tackle climate change and at the same time set the direction for future global climate cooperation and ensure the completion of the inner energy market.

Since then, the European Commission has put forward proposals in line with targets in the three pillars of energy policy. It applies in particular to the so-called third inner market package for gas and electricity, mechanisms for reliability of supply and the development of energy technology, and the climate and energy package in which the directive for the promotion of renewable energy is included. Additionally, both the first and second strategic energy review on reliability of supply results in a new energy strategy to 2020 or 2030.

3.1.1 The EU climate and energy policy up to 2020

A decision was taken in 2007 on the EU’s climate and energy policy up to 2020.

- The EU’s greenhouse gas emissions shall decrease by 30 percent by 2020 under the assumption that other developed countries commit to comparable reductions. While waiting for a global agreement, the EU commits to cutting greenhouse gases by at least 20 percent by 2020 compared to 1990 levels (EU 27).
- 20 percent of the EU’s energy consumption shall come from renewable sources by 2020 and the share of biofuels in the same year shall be at least 10 percent.
- The EU is set to reach a target of 20% energy efficiency improvement by 2020.

Discussions within the EU about the shape of the European climate and energy policy by 2030 have since continued.

3.1.2 Third inner market package for electricity

The third inner market package for electricity was adopted in 2009. Implementation brings about a series of new regulatory requirements and measures designed to increase competition in the wholesale markets and cross-border trade, and to ensure effective regulation and create conditions for investment which are expected to provide benefits to customers. The legislative package also involves new statutory rules through so-called network codes and commission guidelines.

Under the new rules, the Commission has been given powers to expedite the development. Regulators, including the Energy Markets Inspectorate, are given an extended national responsibility to oversee the electricity market and competitive conditions and to certify the system operators. In addition, the European supervisory authority Agency for the Cooperation of Energy Regulators (ACER) was created.

Regional cross-border cooperation should be strengthened on the basis of a so-called bottom-up principle, where system operators and authorities in the region cooperate on network planning, operation and market issues at the same time as the work is followed up at national and European level. Cooperation between systems operators have been formalised by the third inner market package in the European Network of Transmission System Operators for Electricity (ENTSO-E).

The new role assignments mean that the Commission mandates ACER to develop a framework for cross-border trade in electricity and gas, called framework guidelines. On the basis of these designers of ENTSO draft network codes, i.e. more specific provisions based on the guidelines. After the commitology process the Commission states the new rules.

Network codes cover most of the system operator activities – everything from the accession conditions for power plants to the management of transmission capacity in the short and long term. They also relate to power exchanges and electricity trade between member states.

3.1.3 EU energy-climate change framework 2030

In October 2014, the European Council decided on a new climate and energy policy framework to 2030. The framework
contains targets for 2030 related to 1990 levels and, among other things, includes
> reducing greenhouse gas emissions by at least 40 per cent,
> at least 27 per cent renewable energies at EU level, as well as
> at least 27 per cent increase in energy efficiency.

A cornerstone of the framework is a binding target to reduce EU greenhouse gas emissions by 2030 by at least 40 percent compared to 1990 levels. This is an intermediate target towards the long-term objective of the EU’s emissions to be reduced by 80 – 95 per cent by 2050.

The goal of at least 40 percent emission reduction is to be achieved by sectors of the EU emissions trading system (EU ETS) reducing their emissions by 43 percent compared to 2005 and by sectors outside the EU ETS reducing their emissions by 30 per cent compared to 2005. Responsibility for emissions reductions will be divided among the member states of the EU and the European Council has agreed on the main principles for this.

The European Council agreed that the objective of increasing the share of renewable energy by at least 27% should be binding at European level, but the goal has not been divided among member states. This is a distinction from the current climate and energy package towards 2020, containing binding targets distributed among all member countries. The goal of at least 27 percent energy-efficiency improvement is to be reviewed in 2020.

3.1.4 Energy Union

According to the Commission the integration of Europe’s energy markets has given some concrete results. For example, the wholesale price of electricity has fallen by one-third. Consumers have been given more choice, since energy suppliers compete by lower prices and better services. The legal framework has improved competition within the sector.

Despite this, and despite the work on network codes, much remains to be done before the goal of a fully integrated European electricity market can be reached. Import dependence and obsolete infra-structures wanting investment are reasons voiced to steer Europe’s energy policy towards an energy union. Other reasons put forward are high energy prices for consumers, lack of competition and the need to move to a low-carbon economy in order to prevent climate change.

Against this background, the European Council in March 2015 approved the Commission’s proposal to create an energy union with a forward-looking climate policy. The five areas covered by the proposal are reliability of supply, a fully integrated European energy market, energy efficiency, reducing greenhouse gas emissions, as well as research and innovation. Within each area there are proposals on measures that directly affect system operators’ activities:
> speeding up of priority infrastructure projects and reinforcement of the transmission network,
> full implementation and strict enforcement of existing energy regulations,
> strengthening of the legal framework for the reliability of electricity supply,
> more efficient and flexible design of the market to be followed by increased regional cooperation that contribute to the integration of renewable energy,
> increased and more thorough coordination of system operators and a greater role for ENTSO as an organization,
> stronger European legislation with extended legal mandate for ACER for increased independence and special status for the national supervisory authorities,
> review and new legislation related to emission reductions, energy efficiency and renewable energy in order to support the goals for 2030.

EU institutions and member states will continue to work with concrete proposals in the above-mentioned areas. As part of this, the Commission on July 15, 2015 made an announcement on a new electricity market design and a communication on retail markets for electricity. In the announcement of new electricity market design the Commission specifies a wide range of areas and proposals relating to system operators’ responsibility. The Commission will adopt measures to reach the target of a border-free European electricity market with a focus on the consumer’s advantage and mentions, among other things, the following:
> Harmonised support schemes for renewable electricity production.
> Increased opportunities for consumers to participate actively in the market and closer to the operating hour.
> Independent regional control centres with European focus.
> Capacity mechanisms and increased risk awareness.
> Common methods for power forecasting.
> Closer cooperation between TSOs and DSOs.
> Expanded and strengthened mandate for ACER and ENTSO.

Overall, the Commission visualises a governance system to supplement the ordinary legislative work and aiming to coordinate the work of at national, regional and EU-level, to meet the energy union’s objectives.

The Council will report on the work with the energy union to the European Council at the latest in December 2015.

### 3.1.5 The infrastructure decree

In 2013 the European Parliament and Council Regulation (EU) 347/2013 on guidelines for trans-European energy infrastructure – the so-called infrastructure decree – entered into force. The regulation aims to ensure that the infrastructures necessary to meet the EU’s 20-20-20 objective are implemented.

The regulation gives priority to twelve strategic, trans-European corridors and areas for energy infrastructure. It also sets rules for identifying projects of common interest, so-called Projects of Common Interest (PCI), in order to

2. TSO — Transmission System Operator, DSO — Distribution System Operator
3. By 2020 to reduce greenhouse gas emissions by 20 percent compared with 1990, the energy consumption reduced by 20% and the share of renewable energy to be raised to 20 percent of all energy consumption.
achieve the objectives. The regulation establishes a system for the authorisation of such projects. A competent authority in each member state may be assigned a special responsibility to monitor the authorization processes. A maximum permissible time for application review will be introduced as well.

The regulation provides a method of creating a harmonised cost-benefit analysis of PCI project and sets out criteria to determine whether projects are eligible for financial support.

In December 2014, work began to update the network investments to have PCI-status. A decision is expected in November 2015.

3.1.6 EU’s objective of linking electricity networks by 2020

Energy infrastructure has long been high on the European energy agenda and interconnected European energy networks are crucial for ensuring Europe’s energy supply, increasing competition in the internal market and achieving the climate protection targets.

In October 2014 the European Council invited to “a rapid implementation of all measures to achieve the objective of interconnection with a transmission capacity of at least 10% of the installed power production capacity for all member states”.

Within the framework of an energy union with a forward-looking climate policy, the European Council also approved the Commission’s proposal for an interconnection target of 10% by 2020. This objective will be achieved through the implementation of projects of common interest (PCI). The Union’s first PCI list was adopted in 2013 containing 248 projects.

A report from the European Parliament4 contains strong criticism of the process for nominating PCI-projects. The rapporteur felt that the grid companies have too strong a position in their work. In Svenska kraftnät’s opinion the report is in large part based on an exaggerated perception of the role that the National Grid enterprises/operators of these systems have in practice. The national authorities, ACER, the Commission, the Parliament and the Council all exercise a far-reaching control over processes and over the work that ENTSO performs. The selection of projects to be taken up on PCI list is in the end made by the Commission and decided by the Parliament and the Council.

Sweden is well positioned in terms of interconnection with neighbouring countries. Including NordBalt Swedish external links have a capacity of 11,300 MW. We have 39,500 MW installed power in Swedish electricity generating plants, which would imply a theoretical interconnection capacity of 39,500 MW with the outside world, amounting to 40 per cent.

Twelve member states, mainly on the outskirts of the European Union, are today below the target of 10% interconnection of electricity networks in their plans. The Commission has therefore announced an intensification of the work in the regional groups set up under the regulatory decree on trans-European energy networks.

The Commission also continues to take initiatives for enhanced regional cooperation. At the European Council in October 2014, the Commission was given a mandate to “regularly report to the European Council, with the aim of reaching a target of 15% at the latest by 2030”.

A comprehensive legislative work continues at the European level in order to implement the European Council’s decision into EU legislation.

3.1.7 EU strategy for the Baltic Sea region

EU’s strategy for the Baltic Sea region is described in a document that identifies overall challenges, policies and working methods. The strategy aims to strengthen the EU’s commitment to the future of the region and linking cooperation structures at the national and regional level.

An action plan, appended to the strategy, is divided into 15 priority areas of action. Among these some 80 are high-profile measures, so-called flagship projects. Such a flagship area is to improve the availability, efficiency and reliability in the energy markets.

Baltic Energy Market Interconnection Plan (BEMIP)

For the Baltic Sea region the strategy shall contribute to improving reliability of supply, as well as the efficiency of the energy markets in the region. This priority area is closely linked to the special plan for the region’s energy markets – Baltic Energy Market Interconnection Plan (BEMIP) – which has, under the direction of the Commission, been prepared in parallel with the work on the strategy. This includes, among other things, strategic measures to extend the Nordic electricity market model to the three Baltic States.

The implementation of BEMIP constitutes a strategic measure in the action plan. A high-level group monitors the implementation of BEMIP with regard to coordination between BEMIP and the strategy. The action plan also emphasises the importance of renewable energy sources such as bio-fuels, solar energy and wind power – in particular through research, development and demonstration. More cooperation is also needed in order to achieve a better coordination of physical grid planning, regulatory adaptation regarding investments in interconnections and analyses of environmental impact on wind power farms.

During the spring of 2015, the Commission has updated

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the cooperation agreement and the action plan for BEMIP. The aim is to broaden cooperation, in addition to infrastructure and electricity market, and, among other things, include renewable, improved energy efficiency and a possibly cooperation around 2030 goals. The new action plan will require an extended cooperation and commitment between government agencies and ministries in the energy sector with a focus on the Baltic States.

The implementation of BEMIP also concerns Sweden and Svenska kraftnät through a number of infrastructure projects. These include the cable connection NordBalt between Sweden and Lithuania. The purpose of the NordBalt is to link the emerging Baltic electricity market with the Nordic.

Sweden and Svenska kraftnät have a high level of ambition in the work on the strategy and the action plan.

3.2 From the Nordic Region to Europe

The Nordic perspective has for many years been a guiding line for the efforts to develop the electricity market, system operation and network expansion. The development of a European framework in these areas implies a broader perspective.

Nordic cooperation is the basis for Svenska kraftnät’s actions and of great importance as the common EU electricity market evolves. In order to achieve the objectives in the climate and energy area, an effective and borderless electricity market is required. Investments in infrastructure will be crucial to achieving this. For those investments to be feasible, effective planning and decision-making processes are required.

3.2.1 From planning within Nordel to ENTSO-regions

In the previous partner organization Nordel, the Nordic perspective was governing. In the two systems development plans that were prepared by Nordel, strategically important network investments were specified to improve the Nordic electricity market’s functioning, strengthen the Nordic National Grids in order to increase reliability, and remedy limitations in interconnection capacity between the countries. The last systems development plan also identified the benefits of strengthening relations from the Nordic Region to the continent.

Interconnection capacity between the Nordic countries is of great importance for the proper functioning of Nordic and regional electricity market. A greater integration with the world outside the Nordic Region and an increased share of renewable electricity production poses new demands to the transmission grid. The increasing volume of unpredictable electricity production requires higher transmission capacity and more flexibility in the electricity networks.

As part of the adaptation of the Swedish and Nordic transmission grid to the European energy and environmental policies, extensive efforts are made to further increase the interconnection capacity and reliability. Thus planning of the power grid has gone from being national and Nordic to become regional and European.

3.2.2 ENTSO

European Network of Transmission System Operators for Electricity (ENTSO-E) was established in 2009, while Nordel was dissolved. 41 European network companies from 34 countries are partnering within ENTSO. In addition to the EU countries, Norway, Switzerland, Iceland, Serbia, Bosnia and Herzegovina, Montenegro and FYROM (Macedonia) are included in the collaboration.

The work is carried out in the areas of network planning, operations and marketing. ENTSO also has working groups in the areas of law, communication, and research and development.

The work of ENTSO is very extensive and is carried out in a hundred or so working groups with representatives from the systems operators. It has grown significantly since the organization was established.

In network planning, Svenska kraftnät is involved in the Regional Group Baltic Sea. These include Sweden together with the other Nordic countries, the Baltic States, Poland and Germany. Svenska kraftnät is represented in about 50 working groups within ENTSO.

3.2.3 Ten Year Network Development Plan (TYNDP)

One of the major commitments of ENTSO is responsibility for the European network development plan, the Ten Year Network Development Plan (TYNDP).

The reporting of future network development is governed by Regulation (EC) no 714/2009, which requires that the TYNDP should be produced every two years. The aim is to present evidence, analyses and projects for the European network development in order to enhance network planning transparency. The plan also represents decision support at regional and European level but is not formally committing.

The plan specifies current and coming network reinforcement projects of European interest and compiles the latest information available. It forms the basis for consultation with external stakeholders on the development of the European electricity transmission network. The plan is also an important part of the reporting of work with the integration of renewable energy needed to reach EU’s climate and energy targets.

The plan specifies current and coming network reinforcement projects of European interest and compiles the latest information available. It forms the basis for consultation with external stakeholders on the development of the European electricity transmission network. The plan is also an important part of the reporting of work with the integration of renewable energy needed to reach EU’s climate and energy targets.

The basis of TYNDP is common European energy balance scenarios ten to fifteen years into the future. The plan for 2014 and 2016 uses four scenarios, reflecting various developments of the electricity market.

The scenarios are analysed in order to identify the most effective socio-economic investments to meet the objectives. The investment projects included in the plan are those which are deemed to be of European interest in accordance with certain common criteria given. The investments are grouped also to show that, in many cases, several reinforcements made in concert provide the desired capacity increase.

Evaluation criteria comprise, among other things, the electric market benefit, the integration of renewable electricity production, losses and licensing issues. Not all criteria are expressed in financial terms; therefore a simple cost-benefit analysis is not done in the plan. Analyses and identification of potential network reinforcements in TYNDP 2016, called Project Candidates, are made within ENTSO’s online planning regions. For Sweden this is Regional Group Baltic Sea.

The regional groups published these potential networks reinforcements in a regional investment plan in the summer of 2015. The regional plans then form the basis for a joint evaluation of electricity market advantage and profitability in these projects. This evaluation is done centrally within ENTSO for the various scenarios.

Regions may also analyse their own scenarios in addition to those presented in TYNDP. These may therefore differ depending on how different regions have performed their analyses.

As for Sweden and the Nordic Region the following factors should in particular be noted as they will have a major impact on the future development of the networks.

- Continuing large Nordic energy surpluses, especially in Sweden and Norway, that need to reach markets outside the Nordic region.
- The large proportion of power generation, which is unpredictable, both in the Nordic Region and the closest neighbouring countries, primarily in the form of wind power and solar power, causing large need for trade opportunities between countries and regions to balance variations in production.
- The issue of Swedish and Nordic reliability of supply is becoming increasingly in question.
- The future of the Swedish nuclear reliability of supply is becoming increasingly in question.

3.2.4 European network codes

In the context of the third inner market package, the Commission took the view that there is a need for common European network codes. Regulation (EC) 714/2009 indicates a number of areas with a need to develop network codes as well as the process for producing them.

In recent years there has been an intensive work within ENTSO from the standpoint of ACER’s framework guidelines. Draft network codes are prepared by ENTSO within the three main areas connection, market, and operation and submitted to the Commission for decision.

After ACER’s hearing, the Commission presents legislative proposals and member states then decide through the so-called comitology procedure. In this decision-making process, certain network codes have been restated into Commission guidelines. The legal status of the guidelines, however, is the same as for network codes i.e. decisions become directly committing for the member states. Hereafter this plan uses the concept of network codes.

There are a total of ten network codes.
6. The three operational codes OS, OPS and LFCR are expected to merge into one network code.

the Commission how the promotion and use of energy from renewable energy sources is progressing. The sixth and final report is to be submitted in 2021.

All national action plans8 for renewable electricity production in the EU in 2011 contained large increases of the importance of renewable energy sources in the country’s power system. In the first place, solar energy and wind power are expected to create surpluses of electrical energy in many countries. Even Sweden’s national action plan for renewable energy has a major electricity surplus, mainly as a result of wind farm development.

3.3.2 The planning framework for wind energy

The planning framework is not a development goal, but aims to make the wind power visible in the physical planning. Rather it indicates the framework for the national claims that wind-interest has on access to land and water areas.

These claims are substantial, since 30 TWh wind power production is equivalent to almost 6,000 wind turbines depending on their effect and location. By the end of 2014, there were approximately 3,000 wind turbines, with an annual production of 13.5 TWh9.

Today’s planning framework is national, but the Swedish Energy authority has done a regional breakdown of the frame.

3.3.3 Electricity market policy

The objective of the Swedish electricity market policy is to achieve an efficient electricity market with the proper functioning of competition, which provides secure reliable access to electricity at internationally competitive rates. At the same time, connection of renewable production shall be made easier.

Sweden is part of the European electricity market. The spot price is today determined by a common auction where countries from Finland to Portugal are participating. In the Nordic Region, we also have a close cooperation on regulating resources and system operation.

The Government’s mandate to Svenska kraftnät includes promoting a greater integration and harmonization of the Nordic and Baltic countries’ electricity markets and electricity networks, as well as further development of the electricity market cooperation within Europe by promoting an inner market for electricity10.

3.3.4 Advance phasing out of nuclear power

This year’s decision for early decommissioning of four nuclear reactors involves an important clarification of planning assumptions. The decisions result by 2020 in a loss of 2,850 MW of electricity in southern Sweden, which already now is a shortage area.

The basically good energy and power balance will enable Sweden to manage the early decommissioning with sufficient retention of reliability. But margins will be reduced and the system’s vulnerability will increase.

The big challenge comes when the six remaining nuclear power units shall be phased out. Today’s planning is based on their use for 60 years of operating life, that which is until the mid-2040s. Even here, however, earlier closure may become topical purely on economic grounds.

A phasing-out of nuclear power plants incurs an effect problem that must be managed. Development of renewable electricity generation significantly improves the energy balance, but has less impact on the power balance. Therefore the situation cannot be handled only with additional renewable electricity production and development of external connections. Increased demand flexibility and new storage and battery technology will also be important means.

The Administration’s assessment is that there will also be a need for a contribution of new electricity production which can be trusted for planning, i.e. not dependent on the weather. How this may be made feasible at an electricity market where no new production is profitable without subsidies, may be said to constitute the core of the Energy Commission’s mission.

3.3.5 Energy Commission

The Energy Commission was set up by the Government in the spring of 2015. The assignment is to develop the basis for a broad political agreement on the long-term energy policy.

The Energy Commission is put together by parliamentary constitution and has three main tasks. It will review the future needs for energy based on research and knowledge, identify challenges and opportunities for the future energy supply, and create a broad agreement on long-term energy supply.

The Energy Commission shall study and more closely analyse available assessments of how the future need for energy is expected to be met according to various forecasts and scenarios. It will also produce two or more scenarios for supply, transmission, use and storage of energy in the long term.

Based on analyses and scenarios the Energy Commission will identify the changes in the regulations that may be required for a socio-economically efficient development of the energy system and pay particular attention to the electricity supply.

Finally, at the latest by 1 January 2017 the Energy Commission shall produce supporting material for a broad agreement on energy policy, with particular focus on the situation of electricity supply after 2025-2030.

Thus, the Energy Commission’s work focuses on a time horizon beyond this investment plan, but this does not preclude the results of its work from having a major influence on Svenska kraftnät’s investment plans already for the 10-year period.

3.3.6 The electricity regions

On November 1, 2011 Svenska kraftnät split the Swedish electricity market into four electricity regions. Thus, the

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10. Government letter for the budget year 2015 concerning the enterprise Svenska kraftnät within category 21 Energy
Nordic electricity market is divided into a total of 15 electricity regions – five in Norway, four in Sweden, two in Denmark and one in each of Finland, Estonia, Latvia and Lithuania (Figure 1).

Inevitably, constricted parts sometimes arise, known as bottlenecks in electricity networks. One reason for this is that the demand for electricity varies over the year and the day. Therefore the flow through the mains varies, which in practice means that maximum load only occurs in a relatively small part of the time.

Frequently recurring bottlenecks are remedied after a socio-economic valuation by investment in new transmission capacity. However, it is not economically profitable to strengthen networks to such a level that bottlenecks never occur.

To address bottlenecks by increasing the network’s capacity is a long-term measure. At the same time the effect flow – transmission – cannot be allowed to exceed network capacity. Therefore, short-term measures must be taken.

The market model with electricity regions – so-called market splitting or market partitioning – sets limits at the bottlenecks. As a result, price signals make the market adapt to the maximum permitted trade flow rather than the physical interconnection capacity.

During those hours when the transfer capacity is larger than trade flows between the two electricity regions, an area with equal electricity prices is created.

Northern Sweden normally has an excess of electricity production. It includes the bulk of the country’s hydropower, while consumption is relatively low. The opposite is true in southern Sweden. It comprises the country’s population cent-
These effects are extremely important for the choice of route for a line. Intrusion is also considered in Svenska kraftnät’s investment decisions, because it is not meaningful to proceed with projects that cannot be expected to make concessions and other permissions.

The network investments that Svenska kraftnät implements, can be divided into three main groups according to the driving force for investment (see cf. Chapter 5 for a more detailed description of the drivers).

The first group is the reinforcements resulting from the imperative duty for network companies to connect new production. In these cases the purpose of the socio-economic analysis is to identify the network measures that allow the connection of the new production at the lowest socio-economic cost while maintaining reliability. Svenska kraftnät cannot make its own assessment of the fundamental socio-economic profitability by connecting the production.

The second main group is the network investments made to increase market integration. They are based on Svenska kraftnät’s own analyses of needs and demand on transmission capacity in the National Grid and to neighbouring countries. On the whole these reinforcements apply to the internal main lines, i.e. interconnection capacity between the four Swedish regions and connections abroad. In these cases the analysis of network reinforcement is mainly based on a calculation of the socio-economic benefits resulting from the increased transmission capacity.

The third main group is reinvestment in lines and stations. Parts of the Swedish National Grid need to be renewed. In most cases quantifying socio-economic analysis is also not made, when it is quite obvious that the reinvestment can be justified from a socio-economic perspective. On the other hand, quantitative tests may be carried out to assess whether there are other measures that should be taken in connection with a renewal, for example increase in capacity through voltage increase or other upgrading.

Investment in the Swedish National Grid often produces effects outside Sweden, as the Swedish electricity system is highly interconnected with the Nordic and the European. Some effects of grid investments, such as reduced CO2 emissions, even have a global impact. Moreover, many of the electricity market operators are present in several countries. Therefore it is difficult to make a clear demarcation between Swedish and foreign socio-economic advantage.

Svenska kraftnät has a mandate to promote an integrated Nordic and European electricity market. The Nordic Council of Ministers has given clear directives to the Nordic grid operators to implement such National Grid investments that create socio-economic benefits to the Nordic Region. All in all, this means that Svenska kraftnät even considers socio-economic effects that occur outside Sweden in determining National Grid investments to be made.

Svenska kraftnät’s methods for socio-economic analysis

The method used by Svenska kraftnät for socio-economic analysis is based on how a number of parameters change as a result of a net reinforcement.

Various types of model simulations are important tools in the analyses. By means of simulations network impact on the electricity market, supply reliability, and network losses are analysed among other things. These analyses assume various scenarios for development of the electricity market. By means of sensitivity analyses the robustness in relation to the greatest uncertainty factors in these scenarios is examined.

Benefits are calculated in economic terms for those parameters when this is realistic and subsequently expressed as annual averages. These are totalled to an economic net present value based on suitable calculation time and interest rate for the relevant network enhancement.

The resulting benefit value is compared to the cost of the investment in a spreadsheet. This estimate forms part of an overall assessment, which also includes effects that cannot be economically quantified. This may result in an investment being considered profitable although investment calculation shows negative profitability. Similarly, an investment with a positive estimated profitability may be considered unprofitable if non-quantifiable benefits/effects are deemed to have a significant negative impact.

Some main effects that Svenska kraftnät analyses to assess various investments, are the impact on reliability of supply, the impact on transmission loss and so-called electric market benefit. Electricity market benefit refers to the advantage of exporting electricity from cheaper production facilities in one area to another area, replacing more expensive production.

Electricity market benefits are divided into consumer benefits, producer benefits and capacity charges (“bottleneck revenues”). Capacity charges are made by the grid operator when price differences arise between two regions. They are primarily used to fund network investments to prevent bottlenecks in the grid, and are thus returned to the customer group through a better functioning electricity market.

Svenska kraftnät calculates electricity market benefit for network investments affecting trading capacity between two regions, within Sweden or between Sweden and abroad. In Svenska kraftnät’s analysis no assessment is made of the internal distribution of market benefits between producers, consumers and National Grid operators, as the electricity market is seen as one “player” and the benefit is made up simply by the sum of producer-utility, consumer-benefits and capacity charges.

Svenska kraftnät also use life cycle analysis to assess the environmental impact, in terms of resource use and harmful emissions, resulting from the construction, operation and decommissioning of a network facility. These effects can subsequently be balanced against decreased environmental impact, due to increased ability to integrate renewable electricity generation in the system and/or reduced transmission losses.

Other effects on the power system that are analysed where relevant, are effect on cost for counter trade and reserve storage, and the ability to connect renewable production. Even impact on electricity price differences in Sweden is taken into account. Additionally a qualitative analysis is undertaken of the intrusion effects caused by an investment. These include land incursion and local environmental impact.
In the 1990s and early 2000s the driving forces for investment in the network were few and investment levels relatively low. Over the last decade, the situation has gradually changed. Today a large number of forces interact to push network investments.

The changed energy and climate policy is the largest overall driver of network investments today and over the next decade. The National Grid must be expanded in pace with the social development. Government political ambitions are to be completed, without the net being a strong limiting factor.

Today’s forecasts indicate a further major expansion of the renewable production, which will require investment in new connections and increased transmission capacity. Sufficient transmission capacity in National Grids is also a prerequisite for a well integrated, common Nordic and European electricity market. The requirements posed for sufficient capacity and reliability must also be met. Svenska kraftnät’s task is to extend the National Grid in a socio-economic and rational ways to meet these requirements.

All the below listed motives – new connections, market integration and reinvestments – have a bearing on Svenska kraftnät's core regulatory mission, namely to maintain the reliability of the national electricity system. The challenges generated by, among other things, the rising percentage of volatile power generation and the phasing out of four major production facilities are described in more detail in Chapter 5.

4. NETWORK INVESTMENTS DRIVERS

4.1 Connection of new power generation

The number of new connections to the National Grid net increases. The main driver is the large expansion of wind power. This is connected to brand new stations or through increased feeding into existing plants. Many times Svenska kraftnät does not link directly to the wind-power production, but via new networks connecting several smaller production units.

The expansion plans of wind-power entrepreneurs are constantly changing. There are many different parameters contributing to this in joint force, such as licensing processes and rates on electricity and electricity certificates. It is therefore difficult to present a reliable picture of all projects in various stages.

Svenska kraftnät currently has requests for connection of wind power in the order of 18,000 MW. That’s twice as much as all Swedish nuclear power and equal to 75% of the country’s maximum power consumption. All the applications that are presented to the country’s regional network companies for connecting wind power at lower voltage levels come in addition.

Not all of these projects will be realised. How much that will be built is determined ultimately by the design of the certificate system. When in time the expansion can take place is also significantly affected by the lengthy permission processes.

Where the expansion comes is also very important from the network’s point of view. Under the financial incentives to build wind power, there are potential projects, which often many times exceed national expansion ambitions for renewable electricity production.

There is currently great interest in building wind power in northern Sweden. Favourable wind conditions combined with relatively low population density facilitate the potential for achieving economic viability and for obtaining the permits required to build more wind farms. Northern Sweden is a surplus area, why an extension with centre of gravity there leads to a need for increased transmission capacity in the National Grid. It also leads to increased transmission losses, which means increased costs for electricity customers.

The greatest potential for large volumes of wind power at sea is in southern Sweden. High cost, however, makes it difficult to build offshore wind power, other than in very close coastal locations. In general it is better from a socio-economic point of view to build new production in southern Sweden, because the input is then made closer to consumers and commercial connections. A trend towards more wind power in the south therefore to some extent reduces the need for network reinforcements. However, even expansion in the south affects the National Grid, because hydro-power in the north will increasingly be needed as resource regulator for dealing with large wind power variations.

A weak governing factor is the National Grid tariff design. It favours connecting production in southern Sweden, because such production is located close to consumers and
hence reduces the National Grid losses and the need for investment in new transmission capacity.

The electricity region reform works in the same direction. The result is that during periods of transfer restrictions in the National Grid, surplus areas of Luleå (SE1) and Sundsvall (SE2) have a lower electricity price than the Stockholm (SE3) and Malmö (SE4) regions. This marginally degrades the investment scenario for new wind power in the north in comparison with new wind in the south.

Finally, the design of the network enhancements in Sweden is also influenced by how and where new production is being built in the north of Norway and Finland. A larger surplus in these areas will be transported through Sweden for consumption and export links in southern Scandinavia.

All in all, the extensive development of wind power is a significant challenge for Svenska kraftnät in planning the network’s development needs. The great challenge is to identify those development projects that will be realised. There is often considerable uncertainty if and when planned investments will materialise and how extensive they ultimately become. This situation is further underlined by the fact that authorisation processes for expanding the National Grid are usually substantially longer than the corresponding processes to give permission for wind power plants.

In the 1980s and 1990s the effect of the nuclear power stations increased in the order of five to ten percent. Thereafter continuing increases were made in the form of measures for increased efficiency. In the 2000s applications were made for increasing the thermal effect in eight of the country’s ten blocks.

In recent years, the business economic conditions for Swedish nuclear power have deteriorated sharply. Low electricity prices, increased effect tax and increasing contributions to the nuclear waste fund, all push profitability downwards. As a result, the owners have now decided on an early closure of the four reactors put into operation in the 1970s. Svenska kraftnät is not expecting a need for additional network investments during the decade for handling an increased power input from the nuclear plants.

4.2 Bottlenecks and market integration

In order to achieve an efficient electricity market that provides reliable access to electricity at internationally competitive prices, the Government has specifically pointed out that the Nordic electricity market is necessary for the effective use of the common production resources. Bottlenecks in the Nordic electricity network and between the Nordic Region and the continent should be removed.

 Provision of sufficient capacity for increased market integration is a driving force that is continuously analysed. The objectives set by the EU for renewable energy are expected to create an increasing electricity surplus in the Nordic countries, mainly in Norway and Sweden. New wind farms are being planned almost everywhere in the Nordic Region.
but above all along the coast and in the north of Sweden and Norway. New small scale hydropower is being planned in Norway.

Construction of a new nuclear power plant is going on in Finland and another, located in the north of Finland, is under study. Sweden has seen upgrades to the existing nuclear power. These production sources are characterised by low marginal costs, high capital costs, and they are free from carbon dioxide.

To create a picture of the future transfer pattern in the core network, Svenska kraftnät analyses how the new production facilities will be used. This is particularly important in a system such as the Swedish, where a large part of production is located in the north of Sweden while consumption is concentrated in the south.

The Baltic States, Germany, Denmark, Poland and eventually United Kingdom will be the largest potential importers of electricity from the Nordic Region. New connections allow replacement of fossil-fuel based electricity generation on the continent with carbon-free electricity from Scandinavia. Without new foreign connections, there is a risk that production becomes trapped in Sweden and Norway. Prices in the Nordic region and on the continent will converge more and more as new connections abroad are built.

The power system in the Nordic Region is dominated by hydropower, in particular in Sweden and Norway. Production can fluctuate considerably year on year depending on the hydrological conditions. There is a need to be able to balance variations against the continental system, which is mainly dominated by thermal power.

In general, there is also a trend towards larger and faster variations in the effect flows in Europe. This is mainly due to an increase in the proportion of solar and wind. The need for regulating power thus increases significantly. In this context the Nordic hydro-power is an important asset through its ability to vary power production. There are great opportunities to make use of this in trading regulating power capacity.

New links abroad are important to fully exploit the production capacity in Sweden and Norway. A connection between Sweden and Lithuania, NordBalt, is put into operation at the turn of the year 2015/16 and Svenska kraftnät also plans a new connection to Germany.

New foreign links create increased transmission in the National Grid. It puts focus on the internal Swedish bottlenecks – the interconnections – which can be limiting in under certain operational conditions. Svenska kraftnät is therefore aware of the need for domestic grid reinforcements, not only over the interconnections, but also locally in the areas in which new production facilities and links abroad will be connected. For example, a new connection from Skåne to Germany does not only require improving transmission capacity between SE2, SE3 and SE4, but also needs network reinforcements in the east-west direction in the south of Sweden.

The grid in southern Sweden cannot cope with increased transmission in any significant way without reinforcements. Upgrades of old lines may be made by increasing the number
of wires per phase from two to three, and at the same time increase the cross-sectional area of each phase line. This requires, however, in many cases switching to stronger mast-pylons. At the same time, it is difficult to accept interruption, because the wires have high load over much of the year and are important for operational safety.

In many cases, the only option is to build a new line to replace the old one. However, it is difficult to come through with new lines in southern Sweden, which is densely populated and has many areas requiring protection.

Svenska kraftnät implements measures to increase capacity between SE3 and SE4. These include Sydvästlänken and a new line between Ekbyddan (Oskarshamn) and Hemsjö. Svenska kraftnät is investigating the need for additional capacity between SE1 and SE2 and between SE2 and SE3. The driving force behind these reinforcements is even linked to the need for taking old lines out of service for repair work, without getting too much of a negative impact on the electricity market.

It is important that the correct measures are taken at the right time so that reliability is maintained, while at the same time meeting market demand for transmission capacity.

The Norwegian network development plans play an important role. Statnett is planning several new connections abroad. The first step towards greater trade capacity was taken when the Skagerrak 4 connection between Norway and Denmark was put into operation in the beginning of 2015 with a capacity of 700 MW.

Statnett plans to build connections to Germany (NordLink) and the UK (North Sea Link). NordLink with 525 kV and 1,400 MW is 570 km long and will be put into operation by 2020. North Sea Link with the same capacity is 730 km and will start operating 2021. In addition four commercial players – Vattenfall, Agder Energi, E-CO and Lyse will build a 650 km long connection for 1,400 MW between Norway and Scotland.

This increased trade capacity from southern Norway puts great pressure on the Norwegian domestic network and Statnett considers further interconnections, including a new cable to Holland, not to be feasible before further internal reinforcements are in place.

### 4.3 The need for reinvestment

The National Grid plays an important role in electricity supply and is a key part of society’s infrastructure. Society’s increasing dependence on electricity makes ever higher demands on the main network and reliability of supply.

The National Grid’s ability to satisfy customers’ requests for transmission will therefore not decrease as a result of the facilities’ getting older. In 2015 the oldest parts of the National Grid’s areas 400 kV systems approach 65 years old and parts of the 220 kV system are even older. Svenska kraftnät’s responsibility is to ensure that the quality and performance of installations are maintained to meet society’s needs for a robust National Grid.

Reinvestment in existing facilities is therefore as important as investing in new ones. High operational and personal safety are key objectives in Svenska kraftnät’s operations and a continuous renewal of the ageing facilities is necessary to reach them.

In Sweden the use of electricity accounts for a large proportion of the total energy use, such as by Sweden’s large electricity-intensive industry sector. It makes the country more vulnerable during power outages. The large dependency of major functions in society makes extensive and long power cuts hit hard on all sectors and functions.

Facilities are renewed for technical reasons, i.e. when the risk of failure becomes too great. A key insight in this context is that a fault in the National Grid can have major consequences for underlying networks and customers connected to them. In the worst case, disturbances of great magnitude, both in time and number of affected, may occur as a consequence of a National Grid failure. In view of this, Svenska kraftnät cannot delay investments until an accident occurs, but need to plan and implement investments before the technical service life of facilities is reached.

To be able to take action in time, facility status needs to be continuously assessed. Current reinvestment measures are based on an inventory made just over ten years ago. Because several National Grid facilities are approaching their technical service life, a longer-term reinvestment plan is required. Over the last couple of years a comprehensive inventory is being prepared with status assessment of all National Grid facilities. This has been the basis for the present detailed programme and prioritization of the reinvestments required in stations and lines. Status evaluation of installations is a complex area constantly developing, which then has the effect of plans changing to take account of new acquired experience.

Finally, it is worth noting that in order to renew the lines, in most cases they require replacement with completely new ones. Great demands are made for rational methods of implementing the measures – both from an authorization perspective, and to minimise the impact of a major disruption on the electricity market. It cannot be excluded that in some critical areas an additional line can be justified in order to retain existing market capacity during the lengthy process to renew link by link.
5. CHALLENGES

Some of the major challenges facing Svenska kraftnät in the coming decade are reviewed below. The challenges are in both technical, market and authorization categories.

5.1 Operational reliability

According to the directive (1994:1806) on system responsibility for electricity, Svenska kraftnät has such responsibility pursuant to Chapter 8 section 1, the electricity act. As system responsible authority Svenska kraftnät has overall responsibility that electrical installations work together dependably so that the short term balance between the production and consumption of electricity is maintained.

Current technical rating of the National Grid is based on Nordel’s network dimensioning principles from 1992. The rules are based on the N-1 criterion, an international generally accepted criterion for network and operations planning. It is a deterministic criterion, meaning that a system with N components shall have full functionality even if the system is powered by N-1 components, i.e. failure of any single component will not affect system functionality. The operation should be restored to within normal limits within 15 minutes after a dimensioning fault and prepared to cope with a new fault.

A review and evaluation of the Nordic network dimensioning rules and operation safety standards was made in 2004. The conclusion was that there was no motivation to change or waive these rules, but rather to work to ensure that the rules are observed.

On September 4, 2009 Svenska kraftnät formally established the goals of reliability13 that were subsequently approved by the Government14.

The networks dimensioning policies aimed at a balance between reliability and economy and take into account both interruption for maintenance of primary facilities and the potential for disturbances. In the first place requirements relating to the interconnected power system in the Nordic countries are taken into account. The Nordic design rules are recommended to be applied as a basis for decisions on expansions both of the internal National Grids in the Nordic Region and of the connections abroad.

The Nordic power system’s resilience to disturbances is evaluated according to defined criteria set out in view of a risk assessment (risk = probability * consequences).

A system whose function should be unaffected by each individual event must have a design which is resilient to disturbances. In order to obtain high reliability in the national supply the Swedish transmission network, the National Grid, is designed in a mesh connecting hubs by several lines, which means that electricity flows another way without manual intervention when one line drops out.

To prevent weak parts from being built, the system must also be given a standardised design. Dependencies between components must be reduced so that the impacts of malfunctions are reasonably small in a national perspective.

An example of this type of dependency is parallel building of lines where the risk that both lines are disconnected, for example by extreme weather events, is increasing. If the system is not designed for such events, a serious risk is present for the whole or parts of the system to be knocked out. For this reason parallel building is avoided for the National Grid lines. Parallel building also of grid lines and power lines in regional networks can pose a serious risk, as core and regional networks are strongly related to each other.

Each object connected to the National Grid is also a potential source of fault. Therefore, the number of connected objects must be kept within reasonable limits and also be securely connected. The National Grid can be said to constitute highways of electricity supply and a highway may not have a multitude of small entry and exit points. Another aspect to consider is that the system’s ability to resist disturbances must be kept up also during periods when parts of the system are down for maintenance service. This means that, in addition to compliance with the N-1 criterion for intact core network, prerequisites must also be in place for operating the core network under the N-1 criterion when parts of the system are out of service.

The electric power system must be maintained in order to retain reliability and resilience. Maintenance of lines, stations and plant parts requires disruption. To maintain operational reliability, trade capacity must, as a rule, be reduced in the event of disruption at plants. This means that necessary maintenance may in the short term, have a negative impact on the electricity market by temporarily lower trading capacity.

5.2 System challenges

As the renewable production increases and the price of electricity remains at a low level, conventional electricity generation will increasingly be ousted and taken out of service. It has become a reality through E.ON’s and Vattenfall’s announcements in the past two years that it is intended to initiate closure of two blocks in Oskarshamn and two blocks in Ringhals before 2020. The increasing proportion of unpredictable electricity generation and the decommissioning of nuclear power-stations have as a consequence that the power system’s properties gradually change.

Weather dependant, renewable electricity production may be forecasted and planned only to a limited degree. Weather forecasts are also uncertain, especially for more than 24 hours in advance. The weather-dependent electricity generation does at present also not contribute with mechanical rotating mass, frequency or voltage control and therefore cumulatively creates great challenges for the future operation of the power system.

Some of these challenges are discussed below and will represent a need for measures to manage and call for investment to ensure the continued reliability and capacity of the power system.

Power supply

Svenska kraftnät is responsible for the balance between production and consumption being maintained in the moment of operation, that is, that there is enough power to meet the needs of consumption in any given moment. Historically, the availability of power has been critical during high consumption in combination with low availability of nuclear power. Now the production of unpredictable electricity increases more than the conventional and with a high proportion of weather dependent electricity production, conditions will be changed.

It brings a better energy balance but a poorer power balance. The number of cases with high consumption and at
the same time low power generation will increase as a result of the production’s volatility. Gradually, the unpredictable electricity generation risks undercutting conventional power generation. This increases the risk of situations with power shortage - and that electricity consumers may have to be involuntarily disconnected.

This issue is topical in Germany and other countries on the continent where the extensive subsidies to renewable power generation displace conventional production. The latter is not profitable to maintain, since the demand is for such short periods of time although the production is needed at these times. As a result, new subsidies and various kinds of capacity mechanisms are set up in several countries.

This debate is not yet current in Sweden but may become so when phasing-out of Swedish nuclear power begins.

Since 2003 there is in Sweden what is termed a strategic reserve, the so-called "power reserve". The act (2003:436) regarding power reserve came into force on 1 July 2003 and meant that Svenska kraftnät was instructed to trade a maximum of 2,000 MW. This was intended as an interim solution. In its original version the power reserve act would have ended on March 1, 2008. The period of validity has, however, been extended, first to March 15, 2011 and then to March 15, 2020. A third extension, this time to 2025, has recently been announced.

**Power balancing**

Svenska kraftnät is responsible for power balance in the instant of operation. In the planning stage the balance control is managed by a number of balance responsible companies, whose mission it is to plan so that all production and consumption of electricity in Sweden are in balance over the next day. Svenska kraftnät assumes responsibility for balance during the operating hour and adjusts any contractual imbalances by calling for bids for up or down regulation of production or consumption.

The balance control is based on that momentary imbalance may be followed indirectly through the power system’s frequency and that the frequency continuously is returned to 50.0 Hz. The frequency quality reflects the power system’s ability to manage disturbances and maintain stable operation when changes of consumption and production create imbalances by calling for bids for up or down regulation of production or consumption.

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Historically, variations were mainly caused by changes in consumption patterns and current weather conditions. Consumption patterns follow recurring cycles both during the annual different seasons and within the day, making planning and requirements to balance control relatively predictable so far.

The weather-dependent electricity production varies in a stochastic way, further introducing both short and long term variations. This variation in the production segment thus follows no pattern and therefore complicates the balance control.

**Mechanical inertia mass**

Conventional electricity generation, such as water and nuclear power, is done with synchronous generators directly connected to the power network and interconnected via the same. The rotating mass in synchronous generators stores kinetic energy, known as inertia mass.

The strong link between the machines means that they can be seen as one large synchronous machine whose inertia mass represents sluggishness against change in the balance between the driving torque from the turbines and the braking torque from the electric load.

Large inertia mass can be obtained by generator and turbine having either high rotational speed or high weight. This kinetic energy is a first and very important part in a simple and robust power balancing of connected AC systems. If a production site is disconnected, the power output increases on the others, which are then braked somewhat. The frequency drops, causing the automatic frequency regulating power plants to increase their production. If the system’s total inertia mass is large, the machines slow down less and the frequency drop is smaller. Vice versa small system inertia mass causes the braking and the frequency drop to become bigger and faster.

When conventional electricity generation is replaced by large quantities of production, which is unpredictable with
today’s properties, the system’s inertia mass will be reduced. This is because these types of production are not using synchronous machines that are directly connected to the network. The decrease in inertia mass makes the inertia and the first balance regulation of the system disappear, so that the frequency changes more quickly by a disturbance. This is a future operational reliability risk because the system becomes more sensitive to disturbances, which can have far greater consequences than in the past.

The system’s inertia mass is therefore a parameter that becomes more significant to control in the future when the share of solar and wind power in the power system increases.

**Voltage regulation**

Steady voltage in the power system is important both for the capacity of the transmission system in normal operation and for operational reliability in the event of malfunctions. In the National Grid voltage control depends heavily on how much the network is loaded and on the production facilities’ ability to produce or consume reactive power. In steady operation, there is a big difference between the reactive power balance on a low loaded network (low transmission of active power) and a network that has a high load (high transmission of active power).

The network contains shunt reactors and shunt capacitors, installed to manage these variations in the reactive power balance. Equally important are the production plants’ ability to absorb reactive power in surplus situations, and to produce during deficits to keep the voltage within allowable limits. The transmission ability in an AC network depends on the voltage levels in the various parts of the network being kept sufficiently high.

Voltage control at high load depends on sufficient ability to maintain the reactive power balance in all points. The power system’s construction and expansion of production and network have therefore historically been coordinated, so that connected generators are important elements in maintaining the reactive balance and thereby ability to control the voltage in the system.

In the event of malfunctions in the power system, the generators’ ability to supply reactive power is even more significant. If they fail to do so, a voltage break-down may occur at that end of the transmission system which has the weakest compensation. In most of the network’s transmission interfaces voltage breakdown is also the dimensioning factor for transmission capacity. In order not to risk such a voltage breakdown, the connected generators are set up to automatically support the voltage when a fault may occur in the system.

In southern Sweden, there is a strong correlation between the ability of nuclear power stations to supply reactive power and the transmission capacity in the National Grid.

Facilities for renewable electricity production usually do not at present contribute to automatic support of the system voltage. The wind turbines which were connected previously did not have this ability, but most major wind farms now being installed do have it. When the network codes come into force, the demand for voltage control of renewable electricity production will increase.

A large proportion of wind power is connected to the network at lower voltage levels. This means that in the long term, large amounts of production are moved from the National Grid to the underlying network. This reduces the reactive support on the National Grid, which exacerbates the problem.

### 5.3 Market development

Swift implementation of the EU’s target model for the electricity market is required to deal with the challenges to the power system and ensure that the objectives of the EU energy policy are met. The increased market integration with the rest of Europe and the implementation of the future European legislation through network codes are important for this development. It will make demands on Svenska kraftnät to adapt its activities to the European. Therefore a comprehensive harmonisation work is underway, which will include harmonised market rules for all European electricity markets.

**Market integration**

Recent years have been marked by increased market integration between the Nordic electricity market and electricity markets on the continent. In February 2014 the day-before markets in the Nordic Region and North-West Europe
(NWE) were price-linked. This means that the electricity exchanges and system operators in North-Western Europe now calculate market prices and trading volumes of the day-before-trade in the same market algorithm, i.e. jointly at the same time.

In a price-linked market the combined production resources and the available transfer capacity may be better used. This allows a greater efficiency and supply reliability to be achieved within and between countries in the region. Recently even Spain, Portugal, Italy and Slovenia have joined the price linking. As a result, price linkage covers 85% of Europe’s electricity consumption, from Finland in the northeast to Portugal in the southwest.

A project is currently also in progress, which aims to deepen the integration of intra-day markets in the Nordic Region, Central and Western Europe, Switzerland and the UK by establishing a common platform for the cross-border intra-day trade. In conjunction with the growth in Europe of unpredictable production capacity, such as wind and solar power, there is an increasing need for market participants to adjust their balance closer to the operating hour. As a result of the common platform for intra-day trading being established, the market players will have the opportunity to trade throughout the region, thereby improving their ability to adjust their balance ahead of the operating hour.

Increased need for flexibility in production and consumption

The need for flexible electricity generation capacity will increase, to be able to fend off the fluctuations in production caused by renewable unpredictable electricity production. In order to provide market players with sufficient incentives to invest in such facilities, price peaks in the electricity markets in individual hours must be allowed so as to make investment profitable.

To enable a more efficient management of these fluctuations in the weather-dependent electricity generation, bids with finer resolution than one hour are anticipated. Creating opportunities for this will make it easier for players to plan their production and consumption in balance as well as for the transmission system operator to maintain balance during operation hours.

Increased flexibility is not needed just for production plants but also for electricity consumers. By making consumers more active participants in the electricity market by decreasing and increasing their consumption according to the current operations and market situation, efficiency will increase and the need for production regulation resources decrease. It is also necessary for consumer facilities to have appropriate incentives to make more consumers more flexible in their use of electricity. As a first step, it is a question of increasing participation from major consumption centres in industry, but in the longer term greater participation may be invited also from small consumers.

**Balance prices should reflect actual system costs**

The electricity market needs to act in line with the needs for the operation of the power systems. The more the result takes into account the needs of the power system, the less correction needs to be made by the system operator. The balance-responsibles are charged with business planning into balance ahead of the operating hour, but this requirement becomes more difficult to meet over time.

By creating stronger incentives for the balance-responsibles to keep in balance, their behaviour may to a greater extent be brought into line with the power system’s needs. Therefore, it is important that the system cost for imbalances is reflected in the balance prices paid by the players for their imbalances. It gives operators increased incentives to keep their production and consumption in balance.

**Long-term power balance**

Market participants ought to take greater responsibility for the long-term effect balance. For this to happen there needs to be a design for market solutions that can handle large elements of unpredictable production and still provide stable, clear incentives for new power production. There should also be sufficient opportunity for traders to hedge prices. Currently there are no adequate price signals for operators to invest in non-subsidised power generation.

In recent years, several countries in Europe have discussed or already introduced capacity mechanisms to ensure that capacity is available, and to avoid taking conventional electricity generating plants out of service. In Sweden the effect reserve will be extended to 2025 in the light of, among other points, the development that is going on with an impending closure of some nuclear blocks and increasing volumes of unpredictable power generation.

The inner electricity market in Europe should provide equal conditions for all players and therefore a greater coordination of supply reliability should take place both at the regional and European level and special national solutions should be avoided. Otherwise there is a risk that the long-term investment signals from the market are disturbed and that investment only occurs in countries with compensation for production capacity.

**5.4 Technology choices in development of the National Grid**

In the planning of investment in the National Grid the starting point is Svenska kraftnät’s mandate to develop a cost effective, reliable and environmentally friendly power transmission system. The solutions chosen to strengthen the National Grid must also be flexible, so that they can be used in different development scenarios.

**5.4.1 Alternating current and direct current**

The Swedish National Grid, like all National Grids in the world, is designed as an AC-network and as national transmission network able to transfer large volumes of electricity over long distances. AC technology is completely dominant in all parts of the electricity supply and virtually all electricity is produced and consumed as alternating current. It is a
technical design that provides great flexibility and robustness.

The generators’ shaft speed in a synchronous AC system corresponds to a common frequency. This frequency is the same in every part of the system. Thus the frequency represents an effective parameter in a decentralised allocation of duties to regulate the physical balance in the electrical system. Balance regulation in the synchronous electrical system has therefore been built in a simple and very robust way, without need for a complex and vulnerable centralised control system.

The possibility of using alternating current to adapt the voltage levels in the electricity networks is also a valuable property at the local and customer-oriented level. A large number of DC connections are installed all over the world, also in the Nordic electricity system. Today, it is possible to build DC power connections with very high capacity and advanced controllability.

The basic premise of using DC power technology for high-capacity transmission over large distances is that connections can be made to AC networks with sufficient power for feeding and accepting large amounts of electricity. The high DC voltages required can only be achieved if AC networks have high enough voltage or by transformation from these networks.

DC engineering can thus be used to link large disparate synchronous AC systems and to supplement them with controllable transmission capacity. On the other hand, DC technology cannot replace AC systems as the physical National Grid of electricity supply.

### 5.4.2 Overhead lines or ground cable

A special characteristic of AC technology is that – at 400 kV-level – it is not possible to use in ground or maritime cables for transmission at great distances. The proximity between the conductors in the cable causes extreme phase shifts to arise between current and voltage. This means that the electricity that can be made useful, decreases with cable length. Since the National Grid is an AC system, the development mainly uses overhead power lines.

In addition to the cost and difficulty of maintenance, ground cables cause reduced availability and thus reduced reliability compared to overhead lines. Repair time for a ground cable is significantly longer than for an overhead line.

When taken together, the above causes Svenska kraftnät to build 400 kV AC-connections as overhead lines. Only where no other option exists, AC connections are made by cable and then only at short distances (occasional mile). On the other hand, at lower voltage levels overhead lines have been replaced by cables as protection against severe weather.

As described above, it may in some cases be justified to use DC power for technical reasons. This applies, for example when transferring large volumes of electricity over long distances, by transmission over waters or to have greater control of power flow. DC technology is therefore used in submarine cables to Finland, Jutland, Poland, Germany and Lithuania. The project SydVästlänken uses direct current to maximise capacity in interface 4 and for an increased ability to control the flow across the interface.

Whether AC or DC is chosen, overhead lines are always Svenska kraftnät’s preferred option.

### 5.5 Supply continuity planning

For work where there is electrical hazard, security measures must be taken in accordance with good electrical security technical practices, so as to obtain adequate security for those involved in the work. Such measures should be based on a risk assessment.

When working on National Grid installations the predominant method of work is without voltage, i.e. with the plant switched off and grounded.

The concept of reliability is a measure of power system security and ability to resist interference. The concept of adequacy refers, on the other hand to the ability to maintain balance between production and consumption, on the other to transferring electricity between production and consumption. Taken together, these concepts are a measure for the electrical system’s trustworthiness. Operational reliability includes the ability to manage and resist faults, access to backup and conditions for operations recovery. Also included are requirements concerning voltage and frequency with respect to safe system operation.

The operational management and operating planning, as previously described, are based on what is known as the N-1 criterion. This means that the system shall be capable of withstanding the failure of a single component without affecting electricity supply. Single fault at level N-1 of the Swedish National Grid should, therefore, not be critical for reliability of supply. Within 15 minutes, the network operation shall be restored within normal limits and prepared to cope with a new fault.

In some parts of the National Grid this criterion cannot be met where parts of the plant are connected by a radial line. This concerns mainly 220 kV lines. In these parts, a single fault may mean that supply cannot be maintained. In the event of disruption on plants in the National Grid, transmission capacity is reduced and the operation adapted in order to maintain the operational reliability level.

Considerations of electricity supply and electricity market limit the number of simultaneous interruptions in the National Grid with significant impact on transmission capacity. This poses a great challenge for the ability to carry out the large amount of investment projects and maintenance works now being planned.

### 5.6 The authorization process

Licensing processes will be crucial to how quickly the investments required in the networks can come into being.

#### 5.6.1 Concessions

According to the electricity act a concession is required to build and operate a transmission line. Prior to the concession

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**SVENSKA KRAFTNÄT - NETWORK DEVELOPMENT PLAN 2016 - 2025**
decision, it is considered whether a line is appropriate from a general point of view, among others, based on environmental rules, planning and building legislation, and safety requirements set for power lines. Furthermore, a consideration of whether the applicant is fit for practicing network activities.

An application for a licence shall include, besides an environmental impact assessment and information on how general rules for consideration in Chapter 2 environmental regulations are observed, particulars of the transmission requirements that the line shall meet, alternative line routes which the applicant has examined, the results of the consultation that preceded the application, and the voltage for which the line is intended.

The application should, among other things, have as attachments a technical description of the proposed line, a cost estimate, map of the line’s proposed route and description of the land which needs to be used. Even certified lists of owners and dwellers on the land where the line will be stretched, or of real estate that otherwise is required for the facility and a list of the agreements made on the leasing of land for the line, or any barriers for such agreements, as well as a statement of the applicant’s organization must be produced.

Prior to the decision on the concession opinions from relevant county administrations, municipalities, authorities, interest groups, property owners and other interest owners must be obtained.

The Government has authorised the Energy Market Inspectorate (EI) to evaluate questions on network concession. For matters relating to the National Grid lines EI decides on authorization for the line. If appealed, the Government may review EI’s decision on concession. For foreign connections EI prepares the case and makes its assessment, but the decision of concession is made by the Government.

5.6.2 Electric and magnetic fields

An important issue in the licensing processes is the widespread concern for the electric and magnetic fields around power lines.

The voltage between a power line’s phases and the ground gives rise to an electric field. This can sometimes cause electric discharges in the form of light shocks, if one is just below a power line. The phenomenon is unpleasant but harmless.

We are constantly surrounded by the static geomagnetic field, but there is a magnetic field around the grid’s AC lines that change in magnitude with the current’s frequency 50 Hertz. This is not unique to power lines. All electrical appliances that we use generate magnetic fields.

The magnetic flux density is measured in the unit microtesla (mT). A hair dryer will give 30 mT against the user’s head and one who prepares food by an induction cooker is subjected to a magnetic field of 1.2 mT. The field decreases very rapidly with distance from the source.

There is no scientific evidence, which allow determination of the precise limits on how strong the magnetic fields may be. In the absence of such limits Svenska kraftnät applies a precautionary principle, which means that the company prepares measures for existing lines if the magnetic field exceeds a one year’s average of 4 mT where people visit regularly.

By the design of new lines Svenska kraftnät has a substantially higher level of ambition. The applied target is that the magnetic field as an annual average should never exceed 0.4 mT. There are three reasons for this.
The first is that Svenska kraftnät knows from experience that over decades new exploitation is done, making buildings come ever closer to the lines. The second is that the objective takes into account potential new scientific knowledge in the future. And the third is that there are usually relatively marginal additional costs associated when building completely new lines.

It is increasingly common, for example for municipalities when planning in detail or for the Building and Planning authority when responding – without scientific or other basis – to require that the magnetic field levels should not exceed for example 0.2 mT. Svenska kraftnät will therefore draw attention to the risk of a non-factually based practice sliding in the licensing procedure.

Svenska kraftnät estimates that there are about 2,800 residences at the National Grid where the magnetic field exceeds 0.4 mT, and that it would cost in the range of SEK 17,000 million to fix them.

The EU has adopted a recommendation, which is the closest we can get to a European standard in terms of the impact on the public. It recommends the Member States to apply the limit values that the International Commission on Non-Ionizing Radiation Protection (ICNIRP) published in 1998.

ICNIRP limits have been set with considerable safety margins in order to prevent known as well as unforeseen effects of magnetic fields on the human body. The recommendation also says that because of its large safety margins it also covers potential long-term effects for the entire frequency range.

In the summer of 1999, the EU adopted the recommendation (1999/519/EC) on the limitation of exposure of the general public to electromagnetic fields. On that basis the Radiation Safety Authority (SSM) has issued general guidance for the limitation of the general public’s exposure to electromagnetic fields (SSMFS 2008:18). It lists as a basic assumption each local environmental council is now given the opportunity to question this trade-off.

As mentioned above, a concession is required pursuant to the Electricity Act to build and use a power line. In each concession case a full environmental assessment is made under the Environment Act.

A concession, however, is not only a right but also an obligation to transfer power as specified in the concession. An injunction or prohibition under the Environment Act may therefore be incompatible with the obligations arising from the concession granted under the Electricity Act.

In a decision by the Land and Environmental Court of appeal on August 26, 2011, this conflict between the Electricity Act and the Environment Act became evident. There Svenska kraftnät was directed to relocate a line for which the company had had concession for more than 40 years.

Today’s order in concession cases is that the Government, in an overall assessment considers motives for the line and opposing interests that may exist between the network owner and for example an affected municipality. With the Land and Environmental Court of appeal’s prejudicial consequence each local environmental council is now given the opportunity to question this trade-off.

Processes for licensing and land access in the construction of new lines tend to become increasingly time consuming. The reason is usually conflicts between local and global environmental concerns.

Each new power line entails interference with the environment and regularly meets considerable resistance from those affected. Another reason for the lengthy licensing processes is the fact that building a line requires many approvals, as determined by various authorities. Several of the permits relate to land access and environmental impact.

Processing times at relevant authorities and bodies are hard to anticipate and often very long. Lead times of ten years from investment decision to commissioning are not unusual in the case of National Grid extensions. It is above all caused by the long process for granting the concession.

Svenska kraftnät’s view, the granting of authorisations for new transmission lines will be the limiting factor for how quickly large volumes of renewable electricity generation can be introduced in the Swedish electricity system. This is already a fact for several ongoing wind power projects.

Also at the European level, permitting processes have been identified as a limiting factor to manage the EU’s climate and energy targets and they are therefore an important element in the regulation laying down the guidelines for trans-European energy infrastructure that were adopted in 2013.

The time-consuming licensing processes and limited possibilities for financing of the projects have been identified by the Commission as the greatest obstacles to getting the required investments in place by 2020.

5.6.4 Conflicting legislation

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This confused relationship between the various legislations may create barriers for Svenska kraftnät to carry out the tasks in the field of climate and energy policy as directed by Government and Parliament. Svenska kraftnät’s ability to carry out the intentions of this ten-year plan is likely to depend on the elimination of conflicts between laws.

16. M4127-10 The Döshult case.
THE POWER GRID 2015

The Swedish national grid for electricity consists of 15,000 km of power lines, 160 substations and switching stations and 16 overseas connections.

<table>
<thead>
<tr>
<th>Overhead Power Line</th>
<th>Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 kV AC</td>
<td>10,980 km</td>
</tr>
<tr>
<td>220 kV AC</td>
<td>3,550 km</td>
</tr>
<tr>
<td>High Voltage DC (HVDC)</td>
<td>100 km</td>
</tr>
</tbody>
</table>

Figure 2 The Nordic electricity power system
Figure 3: The dividing line between hydro and heat power dominated areas in the Nordic Region and electricity generation in 2014. Source: ENTSO-E.

- **Sweden**: 151 TWh
- **Finland**: 65 TWh
- **Norway**: 142 TWh
- **Baltic countries**: 20 TWh
- **Germany**: 549 TWh
- **Poland**: 146 TWh
- **Denmark**: 31 TWh

Legend:
- **VATTENKRAFT** (HYDRO POWER)
- **VINDKRAFT** (WIND POWER)
- **SOLKRAFT** (SOLAR POWER)
- **BIОBRÅNSLE-BASERAD PRODUKTION** (BIO-FUEL PROD.)
- **KÄRNKRAFT** (NUCLEAR POWER)
- **ÖVRIGT** (MISCELLANEOUS)
6. THE ELECTRICAL SYSTEM

6.1 The Swedish and Northern European Electrical System

The Swedish electric power system is part of the synchronous Nordic system, consisting of Sweden, Norway, Finland and eastern Denmark (Zealand). The Nordic countries are in an international perspective strongly interconnected with many mutual connections, which have been an important precondition for the development of the Nordic electricity market. The strong interconnection also means that the development in one country has a high impact on the other Nordic countries.

The transmission of electricity in the Nordic National Grids is determined by various natural and electricity market conditions. The need for transmission is determined by the supply (production) and demand (use) of electricity in the various regions of the power system. The expected Nordic electricity surplus will result in an increase of the north-south flow to Continental Europe.

The transmission in the Swedish National Grid – and thus also the need for reinforcements — depends on several factors:

> Scope and geographical location of future wind mill farms.
> Future Swedish nuclear power generation.
> Plans for another new nuclear power plant in Northern Finland (Pyhäsjojoki).
> Transmission capacity in Norway and Finland.
> The price of electricity on the continent.
> Export capacity to the continent from Sweden and other Nordic countries.
> The future size and patterns of variation in consumption in the Nordic countries.

6.1.1 Electricity production in recent years

The Nordic power system is a combined water and thermal power system. In the Nordic Region there is a dividing line between the hydropower dominated area in the north and the south where thermal power generation dominates.

Figure 3 illustrates this divide through middle Finland, central Sweden to the south of the river Dalälven and south of Norway and north of Denmark. The figure also shows production in 2014 in the Nordic countries and in Germany, Poland and the Baltic States.

The high share of hydropower production varies greatly with rainfall and inflow. In Sweden a normal year provides about 65 TWh of electricity, but the inflow energy can vary between 50 and 80 TWh. In total in the Nordic countries the inflow corresponds to close to 200 TWh. In 2014 hydro power generation was 64 TWh in Sweden and 214 TWh in the Nordic countries17.

The Norwegian electricity production consists mainly of hydropower, mainly located in the south-west, but also in the northern parts of the country. In Finland, production is diversified with hydro power in the north, nuclear, condensing power and a large element of cogeneration.

The Danish production consists largely of fossil fuelled condensate power, combined heat and power with an increasing proportion of bio-fuel and wind power. In Denmark, the installed wind power is less than 5 GW and just over 1 GW of this capacity is offshore. In 2014, the Danish wind power production amounted to about 13 TWh and represented thus 43% of the total Danish electricity production.

The German electricity production is dominated by fossil-fuel-based thermal power, but also renewable wind and solar production provide significant contributions to the electricity supply. In 2014 the production of wind power in Germany was nearly 55 TWh and solar power approx. 35 TWh.

Nuclear power generation was previously almost a quarter of German electricity production. Since the nuclear accident in Fukushima on 11 March 2011, several German nuclear power plants have been taken out of operation and all German nuclear power are scheduled to be discontinued by 2022. In 2014, the German nuclear power generation was about 92 TWh.

The Polish electricity production consists mainly of fossil-fuel based thermal power. Poland also has a small percentage of wind and hydro power.

The Baltic States are synchronously connected with Russia, Belarus and Ukraine. The total Baltic electricity production was significantly reduced in 2009, when the Lithuanian Ignalina nuclear power plant was shut down for good. The Baltic electricity production is today largely thermal power. Narva in Estonia has the two largest power stations in the Baltic. The fuel consists of shale oil.

The Baltic hydroelectric power is mainly in Latvia along Daugava River and to some extent in Lithuania. The Baltic wind energy output amounted to more than 1 TWh in 2014.

Table 1 shows the installed power in Sweden per production type and region at the year end 2014/2015. Production capacity for hydroelectric power is largely in SE1 and SE2, while nuclear power plants are located in SE3. Most of the wind and thermal power production is located in SE3 and SE4.

Hydropower and nuclear power have the largest installed effect. Wind power accounts for about 14 percent of the total installed effect. Relatively to the annual production, however, wind power stands for a lower share, as output per installed unit of wind power is relatively low. In 2014 wind power accounted for 8% of total electricity production.

The sharp increase in renewable electricity production, mainly in the form of wind power and bio-fuel-based production is illustrated in Figure 4, showing the installed power in Sweden per production type. The installed wind power in Sweden has increased from just over 500 MW in 2005 to just over 5,400 MW at the end of 2014.

The offshore wind power has not broken through in Sweden, mainly due to the higher cost of installation. Tasked by the Government the Swedish Energy Agency has reviewed how support for offshore wind could be shaped, if such support would be considered desirable. The assignment was reported by the Swedish Energy Agency in June 2015.

6.1.2 Electricity use over the last few years

The Swedish electricity use

Sweden has a high use of electricity, which is due on the one hand, on our geographical position with cold winters, on the other hand, a large electricity-intensive primary industry. In Sweden approximately 14,400 kWh are used per inhabitant


<table>
<thead>
<tr>
<th>INSTALLED POWER</th>
<th>SE1</th>
<th>SE2</th>
<th>SE3</th>
<th>SE4</th>
<th>SWEDEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro power</td>
<td>5,176</td>
<td>8,040</td>
<td>2,591</td>
<td>348</td>
<td>16,155</td>
</tr>
<tr>
<td>Nuclear power</td>
<td></td>
<td></td>
<td>9,528</td>
<td></td>
<td>9,528</td>
</tr>
<tr>
<td>Wind power</td>
<td>478</td>
<td>1,467</td>
<td>1,986</td>
<td>1,489</td>
<td>5,420</td>
</tr>
<tr>
<td>Combined heat and power</td>
<td>282</td>
<td>586</td>
<td>4,625</td>
<td>2,868</td>
<td>8,361</td>
</tr>
<tr>
<td>Solar power</td>
<td>i.u.</td>
<td>i.u.</td>
<td>i.u.</td>
<td>i.u.</td>
<td>79</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>COUNTRY TOTAL</td>
<td>5,937</td>
<td>10,094</td>
<td>18,731</td>
<td>4,707</td>
<td>39,549</td>
</tr>
</tbody>
</table>

Good supply of hydroelectric power has historically contributed to low prices and the possibility of building of the electricity-intensive industries. Electricity is an efficient energy carrier, why electricity is also widely used for heating. In 2014 electricity consumption in Sweden was around 135 TWh, used in the order of 30 TWh for heating, of which 20 TWh were temperature-dependent electrical heating. The temperature dependence of electric heating is reflected in the clear seasonal variation with higher electricity usage in winter and lower in summer. The share of electric heat, however, has declined steadily over the last 20 years. Finally, Figure 5 shows the electricity consumption in Sweden from 1990 to date, broken down by industry and other electricity use. Industry’s electricity consumption is strongly cyclical, which is reflected in the decline in electricity consumption during the financial crisis of 2008. After a return in 2010, industry electricity use has continued to decline.

Figure 6 shows the Swedish electricity consumption between 1990 and 2013, divided into sectors. Industry has reduced its electricity use slightly in the latest decade. Electricity consumption in the residential and service have increased slightly, while the consumption for district heating production and in refineries has fallen.

Transport – mainly rail transport – forming a small part of the consumption, has remained at approximately the same level since 2000. Distribution losses have basically remained unchanged and amounts to approximately 7.5% of total electricity consumption.

The Swedish electricity consumption is concentrated in the central and southern Sweden and mainly to SE3. This is shown in Figure 7, which shows the average electricity consumption by 2013-2014, spread over the four regions. The figure also shows annual production per region.

Regions SE1 and SE2 have far larger production – mainly hydro power – than consumption and represent surplus areas. SE3 has a large production from nuclear power, hydropower and cogeneration. SE4 has very low production capacity after shut-down of Barsebäck and a large deficit in the balance between production and consumption.

Electricity consumption in the Nordic countries

Figure 8 shows electricity consumption per week in the Nordic countries during 2014. Sweden has the highest electricity usage. Norway and Finland, however, have a higher electricity usage per capita than Sweden.

The Norwegian electricity consumption is lower than the Swedish but in relation to the population the consumption is high – 125 TWh in 2014. In common with Sweden Norway has extensive mining, chemical and forest industries and a large petroleum industry that also consumes a lot of electricity. Like Sweden, Norway also uses much electricity for heating, making seasonal variations more clear in Norway.

Electricity consumption in Finland amounted to 83 TWh in 2014. Industry, and in particular the forest industry, accounts for a large part of this use. Electric heating is part of the electricity use also in Finland, but seasonal variations are not as great as in Sweden and Norway.

In Denmark winters are warmer than in the other Nordic countries and the proportion of electric heating is relatively low. As a result, less seasonal variations in electricity use. Denmark has a relatively small electricity-intensive industry sector and the total electricity consumption is therefore low in comparison with Finland and Norway, which have approximately the same population. During 2014 approximately 33 TWh were consumed in Denmark and in total 377 TWh in the Nordic countries.

Overall, the Nordic electricity usage has clear seasonal
variations as well as a clear diurnal profile. Figure 9 shows the hourly consumption in the Nordic Region during a week in February and a week in July 2014. Consumption is highest during the daytime on weekdays and lowest during the nights before Saturday and Sunday. Winter also shows consumption peaks during the morning hours and in the afternoon/evening.

The difference between the minimum and maximum consumption during the same week may be close to 20 GWh per hour. These large differences between seasons and between night and day are reflected clearly in the transmission pattern on the National Grid. The operation conditions for the National Grid are very different between peak and low load hours.

6.1.3 Power balance in recent years

Power balance refers to the ability to maintain the instantaneous balance in the power system i.e. the ability of having available production meet the current consumption. In Sweden and the Nordic countries the power balance is most strained during the winter, when it is coldest.

At deregulation in the mid-1990s, there was a surplus in Sweden. At that time, there were a large number of condensing power plants using fossil fuels with high marginal costs.

With the market prices that followed the deregulation21 of the electricity market, the total operation cost is no longer passed on to the consumer. Plants that can count on a price that exceeds the marginal cost only during a few hours become unprofitable. Many of these facilities have therefore been taken out of service and decommissioned. The expansion of subsidised, renewable electricity production in both the Nordic Region and the continent has accelerated this process.

Together with the closure of Barsebäck nuclear power plant, this has meant that the difference between production capacity and use has diminished and that margins towards power shortage have become smaller. If the plans to close two blocks in Oskarshamn and two in Ringhals are realised, it will reduce margins further.

Power balance winter 2011–2015

After two very cold winters, the winter 2011/2012 was characterised by mild weather conditions and the availability of water in the Nordic water reservoirs was very good. Nuclear power, however, had yet another winter with low availability at times. Electricity prices were low and Sweden was a net exporter of electricity practically all winter, apart from the first half of February, when winter’s single cold spell and the highest consumption occurred.

By that consumption peak only six of 10 nuclear blocks were in operation. At the same time the Swedish hydropower produced near maximum available capacity. There were few commercial bids for increasing regulation in the regulation power market and Svenska kraftnät therefore enabled the power reserve.

After 1 November 2011 Sweden was divided into four separate bid areas (electricity regions) for trading in the Nordic electricity market. Price differences between the various regions were small for most of the winter. The exception was the first part of November, when low availability from nuclear power plants in Ringhals and Oskarshamn reduced the transmission capacity over interface 4 to southern Sweden.

Winter’s highest electricity consumption of 26,035 MW occurred on the morning of 3 February. The domestic electricity production at the time amounted to 23,516 MW, while the remaining 2,519 MW were covered by imports from Norway, Denmark and the continent. Power reserves did not have to be activated during the winter to make supply and demand meet in the exchange trading on Nord Pool Spot. On the other hand, the reserve was activated for network reasons, i.e. in order to ensure sufficient margins to maintain...
frequency, for five days in February.

The winter 2012/2013 may be regarded as a normal winter, although it was unusually cold and with a high amount of rainfall in December. The winter’s highest electricity consumption of 26,760 MW occurred on the morning of January 25. The domestic production was then 25,761 MW and net imports from Norway, Denmark, Germany and Poland were 999 MW.

Water supply was good and nuclear energy had high availability - on an average 90 percent and up to 94 percent at consumption peaks. Production record (more than 160 TWh) as well as export record (20 TWh net) were set in the calendar year 2012. During the winter months, there was almost no price difference between the various Swedish regions.

Also not this year did the power reserve have to be activated to make supply and demand meet at the exchange trading on Nord Pool Spot. On the other hand, parts of it was activated on the regulation power market on December 3 and was kept ready to start 3-4 February and 25 January. The aim then was to ensure sufficient margins to maintain frequency.

Winter 2013/2014 was mild with few periods of very low temperatures. In February in particular, the temperature was unusually high. All in all, this led to a seasonal low electricity demand and relatively low prices on the Nordic electricity market. The winter’s maximum consumption occurred on January 13 totalling 24,760 MW, which was 2,000 MW (!) lower than winter 2012/2013.

Vattenfall produced less than in the previous year. In spite of that, Sweden had a net export of 10 TWh in the calendar year 2013, partly because both wind energy and the nuclear plant in Forsmark hit new production records. Power reserves never had to be activated.

The winter of 2014/2015 was also very mild, with some bad weather and shorter periods with lower temperatures. The winter’s maximum consumption occurred on 29 December and amounted to 23,390 MW, which was approximately 1,300 MW less than the winter maximum 2013/2014.

Electricity prices were relatively low throughout the winter, which may be explained by the mild weather, a strong production and a drop in electricity use. For most of the winter period Sweden was a net exporter of electricity, except for a few short periods at the end of December and in the middle of January.

In the middle of December the storm Ivar passed through the country. Ahead of the storm Svenska kraftnät chose to put parts of the power reserve on standby for two hours. The storm was not as severe as expected and the power reserve never had to be activated. Thanks to the mild winter and a good production availability in Sweden the power reserve remained unused even during the rest of the winter period.

6.1.4 Transfer patterns

North-South flow and the Nordic interfaces

The flow through the Swedish National Grid runs mainly in a southerly direction from SE1 and SE2 that are surplus areas, to SE3 and SE4, which are deficit areas. During daytime the flow usually runs further south via the foreign connections to Denmark, Germany and Poland.

During a normal year net imports go from northern Norway to SE1. The flow goes mainly to the south through Sweden. Flows may also occur from northern Norway through interface 1 and via SE2 to the middle of Norway, which is a deficit area.

Within Norway the transmission pattern is in part a southern flow from northern Norway, and in part an easterly flow from surplus areas in southern and south-western Norway to the Oslo area. The maximum trading capacity in the Hasle interface is used for much of the time in a normal or a wet year. Like the Swedish connections to continental Europe, the Norwegian ones are mainly used for export to Denmark and the Netherlands.

In a dry year Norway has import requirements and to exploit its potential as a European regulator resource and to export electricity during daytime, Norway needs to take back power during low load time. During these periods the flow goes from the continent to Norway.

A north-to-south flow also characterises the transmission in the Finnish National Grid. Flow through the Finnish inter-
face P1 is generally in a southerly direction. Links between SE1 and northern Finland are used during wet and normal years for export from Sweden. During a dry year the reverse can occur. Transit flow may even occur from SE1 through Finland and back to SE3 via Fenno-Skan.

In the Baltic States flow is normally from Estonia southwards to Latvia and Lithuania. Estonia also has a net import from Finland in a normal year. In recent years the Baltic countries have imported electricity from Russia and Belarus. During wet years the flow becomes greater southwards. Exports from Norway and Sweden to the continent and to Finland then increase. In a dry year the southern flow and export diminish.

In the Baltic countries, Latvia has a power deficit on an annual basis. However, Latvia may export to Lithuania as well as Estonia during the spring flood in wet years. Net flows that usually go from Estonia to Lithuania can then change direction and imports from Russia and Belarus to the Baltic States are reduced as well. During dry years imports from Russia and Belarus to the Baltic States also increase. Then the flow southwards from Estonia to Latvia and on to Lithuania is reinforced as well, which can lead to transmission limitations between Estonia and Latvia.

Imports, exports and net flows through the Swedish interfaces

The many connections between the Nordic countries create opportunities for the export of electricity from areas with a lot of hydroelectric power when there is good supply of water, to those who mainly have thermal power production. Conversely, imports take place when the inflow and water availability are low. This opportunity for electricity exchange between countries and regions has meant that the risk of electricity shortage is small in the Nordic countries.

The left map in Figure 10 shows net flows by the Swedish interfaces in 2008, 2010, 2012 and 2014. The right map shows the minimum, maximum and median flow during years 2005-2014.

Table 2 shows output per energy type in relation to consumption and exports/imports in each year. Flow through the Swedish interfaces is typically southern from surplus areas in the north to deficit areas in the south. As Figure 10 shows, the southern flow through the Swedish interfaces was highest in 2012. It was above all caused by the hydroelectric power production during the year being relatively large and that Sweden had large net exports.
Consumption was high during 2010. The transmission to SE4 corresponded to the deficit in SE4 and net exports to the continent were small. In 2014 exports were large, in particular to Finland. This explains the low transmission over interface 1.

**Large diurnal variations**

The left map in Figure 11 shows the flow on January 11, 2012 between 03:00 and 04:00 o’clock. The right map shows the flow on the same day between the hours of 16:00 and 17:00.

The figure illustrates the variations in flow between night and day. Transmission at night and to some extent even during weekends, when consumption is lower, is characterised by a smaller southern flow than during daytime. Flow during the night through interface 1 can even turn around and move in a northerly direction during certain hours. Flow through the connections between SE1 and northern Finland normally runs in the direction towards Finland also during the night.

During the night when consumption is low, the price of electricity drops. This provides incentive for hydropower producers — that can regulate their production quickly and at a low price — to reduce their production. The thermal power plants on the continent, on the other hand, are not closed.
during the night, which is why importing often takes place during the night via the intercontinental connections. A large wind power production on the continent can reinforce this import-dominated transmission pattern.

When the flow is from the continent towards Sweden and on to Norway, the west coast interface may limit the northern route. Production at Ringhals then becomes crucial whether the interface becomes limiting or not.

**Annual time-dependent variations**

Spring flood begins in southern Norway, increasing exports from Norway to continental Europe and Sweden. Next spring flood comes to the north of the Nordic Region. Then the southern flow is reinforced in particular in Sweden but also in Norway and Finland. The reason is that the hydropower producers to a higher degree are required to produce electricity even during periods of low prices. During this part of the year exports from Sweden and Norway to the continent are increasing.

During the summer the consumption is low. Maintenance work on networks and production facilities is done then. The southern flow is usually high during the summer months, when the Swedish nuclear power plants have their revision shut-down. In summer time the flow through the connections between the Nordic Region and the continent during the day usually goes in the direction towards the continent and Sweden imports electricity from southern Norway.

In the autumn the southern flow will be a bit lower than in the summer. The flow is, however, strongly dependent on the weather. Much rain as well as prolonged maintenance operations on nuclear power plants lead to an increased southern flow.

During winter consumption is high and the southern flow is relatively stable.

## 6.2 The development of electricity systems to 2025

EU climate goals mean, among other things, expansion of renewable electricity production in Europe. This expansion consists of new capabilities (wind, solar, water) as well as conversion of existing production to new fuels.

### 6.2.1 Svenska kraftnät’s baseline scenario

Network development plan 2016-2025 is based on a scenario describing what is now seen as a likely/reasonable development until 2025 and that varies depending on the issue under consideration. This scenario should not, however, be construed as a forecast. Table 3 shows the installed generation power and annual electricity use in the Swedish regions in the baseline scenario for 2025.

**Updated assumptions**

Since the Perspective plan 2025 was prepared, some assumptions have been updated. The scenarios used in the Perspective plan 2025, however, remain valid in the sense that they describe well the variations around the baseline scenario.

The new assumptions made since Perspective plan 2025
was prepared, primarily concern nuclear power, wind energy and electricity use.

In the Perspective plan 2025 nuclear energy was anticipated to continue to be produced at the same level as before. Today we know that the owners will take four blocks out of service sooner, even before 2020. For the other six blocks, built in the 1980s, the plan assumed that they will produce electricity for 60 years, i.e. until the mid-2040s.

A nuclear power station does not have a fixed technical lifetime. It is ultimately an economic question how long the plant will be operated. Over time steadily increasing reinvestments need to be done, though, to maintain reliability and availability.

Wind power has been built faster than what was adopted in the Perspective plan 2025. Besides a major part of the planned wind parks will be located in SE1 and SE2, compared to existing parks mainly being found in SE3 and SE4.

Electricity consumption is also expected to be clearly lower than expected in the Perspective Plan 2025. In the Energy Authority’s long-term scenarios for the Swedish energy system in 2014, the assessment is unchanged use of electricity until 2025.

Uncertain factors
A scenario 10 years ahead contains many uncertainties. The biggest ones are deemed to be the same factors as in the previous section, i.e. nuclear power, wind power and electricity consumption.

Uncertainty over nuclear power is about when the blocks eventually will be taken out of service. The facilities will be operated as long as they work and are profitable but today several factors indicate diminishing profitability. This is because of an energy balance continuing to appear strong, which keeps down the spot price.

Wind power development is controlled largely by the electricity certificate system even if production costs are now starting to reach levels where wind power is competitive even without subventions. The uncertainty is partly whether the spot price may fall further so that investments are becoming trapped, and partly the extent to which the electricity certificate system and other potential support system will continue to bring renewable power into the market.

Electricity use is influenced by several drivers that can justify both increased and decreasing use. Here we see a mix of market and political decisions, and it’s not clear which will weigh most heavily.

Hydro power
Hydroelectric power in Sweden and Finland is considered to be fully developed. The undeveloped Swedish rivers are protected from exploitation through legislation and a significant increase in Swedish hydropower production is not possible without changes in the law.

Renewal of older power plants can provide some power increase, but not a major energy boost. In Norway, however, expansion of hydroelectric power is expected, especially in northern Norway and in the West Country. Concessions have been granted for about 3.7 GW and another approx. 3.6 GW are under application or are under investigation22.
Climate change is considered to be able to provide increased inflows and thus an increase in annual production\textsuperscript{22}. On the other hand there is interest to improve the local environment along rivers and streams. These actions may lead to approximately 1.5 TWh lower annual production of Swedish hydro-power\textsuperscript{24}.

**Wind power**

Comprehensive expansion plans have been prepared for wind power. Sweden currently has identified wind power plans in the order of 31 GW installed capacity\textsuperscript{25}. Only some of these will be realised and great uncertainty prevails on the geographical localization.

The classification into regions has resulted in relatively higher rates in the south of Sweden and relatively lower in the north. In the long term this should be a stimulus for expansion of production capacity in the south of the country. Wind conditions, however, are better in northern Sweden and more sparse settlement may facilitate the licensing processes.

The largest installed power is in SE3 but most new projects are localised in SE2\textsuperscript{26}. According to Swedish Wind Energy’s mapping of wind power projects the equivalent of 760 MW was under construction at the beginning of 2015. Projects equivalent to just below 500 MW were localised in SE2. According to the same survey an additional 1,000 MW wind-power has all permits completed. Of these projects about 300 MW capacity was located in SE2.

In the Energy Authority’s long-term scenarios for Sweden’s energy system 2014\textsuperscript{27}, electricity production from wind power is estimated to 16 TWh in 2020. There was also a high scenario with 19 TWh wind power by 2020. Other players make other projections of wind power development. In January 2015 Swedish Wind Energy presented three scenarios for wind energy by 2018. They estimated production at between 15 and 22 TWh with a forecast of 19 TWh. In Svenska kraftnät’s baseline scenario Swedish wind power production is expected to increase to about 23 TWh in 2020 and 28 TWh in 2025.

Offshore wind energy represents a very small percentage of the installed power in Sweden. Two important factors for the expansion of offshore wind power are technology development to bring down procurement cost, and licensing processes, where targets for renewable energy production collide with for example offshore natural reserves and defence forces’ interests.

Wind farms further out to sea have to be coupled to the National Grid area with DC connection. Such investments are impossible to recoup, unless special support is introduced for offshore wind power. Provided that good wind locations are found close to the coast and on-shore, it is highly questionable whether such support is socio-economically justified.

Also in Norway, Finland and the Baltic States many new wind turbines are planned\textsuperscript{28}. The expansion is, however, not expected to be as great as in Sweden. In Norway small scale hydropower, Swedish wind power and bio-fuel based energy all compete for space in the Swedish-Norwegian electricity certificate system. In Finland support is provided via the feed-in tariffs, up to a maximum of 2,500 MW.

In Germany further increase is expected both in land-and sea-based wind power. The German system of feed-in tariffs also provides good profitability even for expensive wind projects. In Denmark there are plans for more expansion of wind power, both on land and at sea.

**Bio-fuel based heat power**

In Sweden a certain expansion of bio-fuel based CHP and back-pressure plants is expected as a result of financial incentives through electricity certificates. How the bio-fuel based electricity production evolves also depends to a large extent on future fuel prices. If the prices of emission rights and fossil fuels go up, bio-fuel based production becomes more favourable.

Conventional heat power production is controlled largely by heating needs. Increased profitability for bio-fuel based electricity production may lead to increased deployment of more flexible production facilities with greater ability to vary power generation independent of the heat requirements.

At the same time, there is a debate about the environmental impact of bio-fuels where opinions differ about the advantages of a bio-fuel heated electricity production. Currently the forest industry is responsible for 93% of the electricity production from industrial back pressure. In the Energy Authority’s long-term scenarios\textsuperscript{29} CHP in 2020 is expected to be 21.2 TWh, of which 7.2 TWh from cogeneration in industry and 14 TWh from cogeneration in district heating systems.

Finland, Denmark and the Baltic States have plans to expand bio-fuel-based heat power.

**Solar power**

Electricity produced in solar power plants is growing rapidly on the continent, especially in Germany. Technology has improved, but the main reason for the rapid growth in Germany is highly favourable support for solar-based electricity production. The technical development is rapid and solar cells could soon be cheap enough for solar power to be competitive without subsidies.

Sweden’s geographical position makes usable time for solar power shorter in Sweden, Norway and Finland than on the continent. That makes solar power less attractive here. In spite of that solar power in Denmark has been developed and produced 476 GWh in the year 2014.

27. ER 2014:19; http://www.energimyndigheten.se/Statistik/Overgripande-rapporter/.
29. ER 2014:19.
In Sweden, 79 MW is installed. From a system’s point of view continued expansion of solar power in Sweden is not desirable. That’s because solar power mainly provides electricity when not needed, that is during the summer months when demand is low. Even today, the electrical system has problems with too much production during this time. From a system’s point of view further subsidies to install solar power are therefore not desirable.

Nuclear power
The dismantling of Swedish nuclear power has now been initiated. The owners have said that the processes have begun to close the four blocks from the 1970s, Oskarshamn 1 and 2 and Ringhals 1 and 2. Precise ending year has not been announced, but by 2020, these four blocks may have been taken out of service.

Such a closure would be equivalent to a reduction of the installed power in the system with 2,850 MW. Over the last five years the average production from these four blocks has been 14.6 terawatt hours (TWh), compared with nuclear energy’s total average production of 60 TWh.

As noted in the preceding, nuclear power has a significant consequence for supply reliability. Any replacement establishments in Sweden and any new construction in northern Finland have a high impact on the Swedish National Grid.

In Finland, there are four nuclear block in operation – two at Loviisa and two at Olkiluoto. A third block is being built in Olkiluoto, with plans even for a fourth one. In addition Fennovoima is planning to build one block in a new nuclear power station in Pyhäjoki in northern Österbotten.

Also in Lithuania, Poland and Russia’s Kaliningrad plans for new nuclear power exist, but no decisions have been made. Germany has decided to phase out their nuclear power by 2022.

6.2.2 Electricity use
Electricity use has historically been affected by population growth and economic growth. In the Nordic Region there is also a relatively high proportion of electricity for heating, which has also contributed to large temperature dependence in electricity use.

Before the financial crisis in 2008 electricity use increased, both in Europe and in the Nordic region and Sweden (Figure 12). After the financial crisis that pattern has changed and electricity consumption has stabilised.

A few factors tend to be prominent when evaluating the future electricity usage, namely energy efficiency, transport and heating/heat-pumps. When it comes to Swedish electricity use, it is Svenska kraftnät’s assessment that these factors basically will be in balance over the next ten-year-period.

Efficiency increase may result in a reduced electricity use. Historically, increased efficiency, especially in industry, however, has led to an increase in electricity use when various industrial processes have been converted from fossil fuels to electricity. In Sweden, the use of fossil fuels is at present relatively low (except in the transport sector), which is why the potential for increased electricity usage is relatively limited.

For transportation there is a clear potential for increased electricity use. Still, a significant increase is not expected over the next decade. Sweden’s railway network is already well utilised and it takes time to build new tracks such as for high-speed lines. The number of electric cars is increasing but the introduction will take a long time, in part as a result of an inadequate infrastructure for charging.

Another factor affecting electricity use is, of course, the market and how users react to the price of electricity. Households are currently relatively insensitive to the price of electricity. Partly because electricity represents only a minor part of the energy bill and also because, although households profit by consuming less power, they rarely shift their consumption in time.
Introduction of time measurement gives consumers an incentive to change their consumption pattern over the day or the week. A recently published report\textsuperscript{30} points out, however, that price differences are too small to be worthwhile on a purely financial basis. The willingness of households to contribute to social benefit, should not, however, be underestimated. Households with electric heating always also have an incentive to keep down their electricity use.

Major electricity users, such as industries, base their investments on long-term stable (and low) price levels. Despite today’s relatively low spot prices, the interest for electricity intensive investments seems to be low. The price level is affected by politically decided instruments, which can change at short notice. A coming dismantling of Swedish nuclear power is also an uncertainty factor, both with regard to energy and power balance, and for price levels and reliability of supply.

The Swedish electricity use has historically been highly correlated to economic growth. Forecasts for economic development therefore play an important role in the assessment of the future electricity use. Other important factors include population growth, energy and climate policy, lifestyle changes and technology development.

### 6.2.3 Energy balance

Energy balance means the difference between the annual produced electricity and annual consumption. A negative energy balance means that Sweden has to import electricity from abroad while a positive means a net surplus that can be exported. The greatest impact on electric energy-balance in Sweden and the Nordic countries comes from the availability of water in hydroelectric reservoirs.

Sweden, Norway and Denmark are expected to have a positive energy balance in 2025.


### Table 3. Estimated installed capacity per electricity region in 2025 (MW)

<table>
<thead>
<tr>
<th></th>
<th>SE1</th>
<th>SE2</th>
<th>SE3</th>
<th>SE4</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro power</td>
<td>5,200</td>
<td>8,000</td>
<td>2,600</td>
<td>300</td>
<td>16,100</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>0</td>
<td>0</td>
<td>6,700</td>
<td>0</td>
<td>6,700</td>
</tr>
<tr>
<td>Wind power</td>
<td>1,300</td>
<td>4,100</td>
<td>2,900</td>
<td>2,200</td>
<td>10,500</td>
</tr>
<tr>
<td>Combined heat and power</td>
<td>300</td>
<td>700</td>
<td>3,300</td>
<td>1,200</td>
<td>5,500</td>
</tr>
<tr>
<td>Solar power</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td>Condensate power and gas turbines</td>
<td>0</td>
<td>0</td>
<td>1,700</td>
<td>1,600</td>
<td>3,300</td>
</tr>
<tr>
<td><strong>THE WHOLE COUNTRY</strong></td>
<td><strong>6,800</strong></td>
<td><strong>12,800</strong></td>
<td><strong>17,300</strong></td>
<td><strong>5,600</strong></td>
<td><strong>42,500</strong></td>
</tr>
</tbody>
</table>

\begin{figure}
\centering
\includegraphics[width=\textwidth]{energy_balance_chart.png}
\caption{Simulated energy balance in 2025 for the Swedish regions.}
\end{figure}
Finland on the other hand shows a deficit which, among other things, is due to delayed nuclear power project and that condensate electricity has been moth-bagged.

The surplus in Sweden and Denmark is due to the development of renewable electricity production. Figure 13 shows the simulated energy balance year 2025 for the Swedish electricity regions. Compared to the present situation, the surplus in SE2 increases because of wind power development, while the balance in SE3 deteriorates since the announced shutdown of several nuclear blocks. Anticipated installed capacity by 2025 is shown in Table 3.

Again, it is important to point out that the development of wind power is uncertain both regarding capacity and location, which affects the assessment of future energy balances.

Net flows between the Swedish regions (cf. Figure 14) exhibit similar patterns as today. In particular, the flow between the SE2 and SE3 is expected to increase because of development of wind power in SE2.

6.2.4 Prediction of power balance and the likelihood of power shortage

By definition, power shortages occur when the Svenska kraftnät needs to use the interruption back-up to cope with electricity supply. The interruption back-up is intended to restore the power system to normal operation after a fault in production plants or power lines. When the interruption back-up needs to be used, power system reliability is reduced and further disorders can lead to power outages.

In SE1 and SE2 the available production capacity is mainly from hydro-power and is significantly larger than the consumption. The probability of power shortage here is very small. The probability of power shortages is currently greatest in SE4, where production capacity is small relative to consumption. During cold winters when consumption is high, SE4 is dependent on imports from surrounding regions to prevent power shortage from occurring. As nuclear power is phased out, the power question will become increasingly obvious even in SE3.

New production capacity is obviously the primary measure to reduce the risk of power shortages. The most important network measure is reinforcement of transmission capacity on interface 2. Increased import opportunities, i.e. new interconnections, can also prop up the Swedish power balance.

New interconnections increase the opportunities for trade with the outside world and contribute to reliability of supply. They are, however, no guarantee against power shortages from ever occurring, especially when systems with large elements of weather-dependent electricity generation are linked together. There is, for example, often little wind in Denmark and northern Germany when the wind is also weak in southern Sweden.

A way to evaluate the possibility of power shortages is making projections for power balance. It gives an indication of Sweden's ability to meet the instantaneous electricity supply in the winter.

Figure 14. Simulated net flows between Swedish regions 2025.

Svenska kraftnät annually submits a power balance report to the Government. The report evaluates the previous winter and makes a prediction for the energy and power situation in the next. The reporting has been requested by the Government ever since the Barsebäck nuclear power plant was shut down. The aim is for the Government to be able to form an opinion on how Sweden shall cope with the electricity supply on the coldest days during a coming "normal" winter and a so-called ten-year winter.

Because all installed power is not available all the time, Svenska kraftnät makes assumptions about what power may be available. Here the differences between different power types are large.

Wind power is highly volatile. This means that the power delivered during the hour with the highest consumption varies greatly. There is no objective truth about which availability of power is the right one. But as the power balance reports’ ultimate purpose is to evaluate how we will cope with the coldest days, it has not been deemed reasonable to use an average for wind power production for an entire season.

Historically, the Svenska kraftnät has assumed that six percent of the installed power is available during 90 percent of the time. This availability figure is based on a study that
once was made by the planning committee in the Nordel cooperation.

Prior to the power balance report 2013 Svenska kraftnät made a new evaluation by studying the duration curves for wind power production in 2011 and 2012. The energy that was produced during 90 per cent of annual hours corresponded to 7% of the installed power. When the power back-up was activated during a day, the figure was just under six per cent of installed capacity, which cumulatively led to the company not finding reason to depart from the old assumption of six per cent availability.

Until now the availability figure has been calculated for wind power production throughout the year. More accurately it should, however, just take into account the four winter months, to which the power balance reports refer. Since the wind blows more in winter than in summer, it has led to a revaluation of the availability figure.

In the power balance report that Svenska kraftnät submitted to the Government in June 2015, it was therefore assumed that 11% of the installed power be available. This new availability figure represents the median value of the tenth percentile for the wind power produced power during the five previous winter seasons (i.e. lower values occur during 10% of the time).

The assumptions for availability of nuclear power are also not self-evident. In the latest power-balance reports, it was known in advance that certain nuclear power generation would be turned off during the coming winter. Availability was then calculated on the basis of this knowledge, along with the assumption that other nuclear power will produce 90% of the installed power. For the power balance reports 2013 and 2014 this meant assuming a total of about 84 per cent availability in nuclear power plants. If the oldest blocks were taken out of service, an assumption of about 90 per cent availability for the remaining appears to make sense. Overall, these results, along with the new assumption of eleven per cent availability for wind power, lead to the forecast power balance being reduced by 1,700 MW by 2020 and with 7,000 MW by 2050.

Sweden has well developed trade links with neighbouring countries. With regard to the power issue, it is important, however, to remember that connections are not everything. The neighbouring country must also have a surplus situation, which permits export links to be used.

At the regional level, SE1 and SE2 in northern Sweden will continue to have a strong power balance. However, power balances in SE3 and SE4 deteriorate when winding down of nuclear power begins. New wind power certainly brings electricity, but not power to the same extent and not necessarily when required.

The Swedish Energy Agency analyses every two years the energy system’s long-term development. Four alternative scenarios are presented for the electricity sector. In addition to a reference case based on currently known conditions, three cases of sensitivity (greater economic development, higher fossil fuel prices and lower production costs for wind power) are reported.

In the latest long-term forecast it was estimated that wind energy in 2020 will be producing 16 TWh, except in the scenario with lower production costs for wind power where production instead was estimated at 19 TWh. Swedish kraftnät’s estimated production of 23 TWh in 2020 would thus mean an increase of about 8 TWh compared to today’s level. This corresponds to an additional 2,750 MW installed capacity by a time of use of about 2,900 hours per year.

By 2050, most or all nuclear power is expected to be taken out of service. This means that the installed capacity today of 9,385 MW disappears. What wind power could produce in 2050 we have no idea. But there are expectations that production could reach a magnitude of 50 TWh, which in this case would mean an increase by almost 40 TWh compared to today’s level.

Technological development means that wind turbines become more efficient. Fewer MW need then be installed to reach a certain energy production. If the usage period can increase by 20 per cent – from 2,500 to 3,000 hours per year – it means that the 40 extra TWh could be produced through installation of an additional 13,000 MW of wind power.

ENTSO has the ambition to present standardised power

| TABLE 4. PREDICTION OF POWER BALANCE IN A "BEST-ESTIMATE" SCENARIO. (GW) |
|-----------------------------|-----------------------------|-----------------------------|
|                             | JANUARY 2016 19:00 | JANUARY 2020 19:00 | JANUARY 2025 19:00 |
| Nuclear power               | 9.1              | 6.9              | 6.9              |
| Fossil-fuel-based thermal power and waste burning CHP | 5.5              | 5.5              | 5.5              |
| Land-based wind- power      | 5.8              | 8.0              | 9.9              |
| Off-shore wind power        | 0.2              | 0.2              | 0.2              |
| Solar power                 | 0.0              | 0.0              | 0.4              |
| Bio-fuel based combined heat and power | 2.9              | 3.1              | 3.1              |
| Hydro power                 | 16.2             | 16.2             | 16.2             |
| TOTAL PRODUCTION            | 39.7             | 39.8             | 42.1             |
| Unavailable capacity        | 9.8              | 10.5             | 12.6             |
| Available products          | 28.7             | 28.2             | 28.4             |
| Cargo                       | 22.2             | 22.8             | 23.1             |
| Reserves in the reduction of consumption | 0.3              | 0.8              | 0.0              |
| “Remaining Capacity”        | 3.1              | 2.4              | 1.7              |
| “Adequacy Reference Margin” | 3.3              | 3.4              | 3.4              |
| IMPORT CAPACITY             | 10.34            | 10.44            | 11.79            |
| EXPORT CAPACITY             | 10.58            | 10.38            | 11.63            |
balance forecasts for all member states. In these forecasts, however, some assumptions and the way that forecasts are presented, differ from the Svenska kraftnät’s power balance forecasts.

Table 4 is taken from ENTSO’s power balance forecast for 2016-2025. It shows power balances in a “best-estimate” scenario. Balances apply to the third Wednesday in January between 18:00 and 19:00. As the table shows, it is expected that the installed production capacity for wind and bio-fuel-based energy increases. The available capacity does not increase significantly, however, because wind power is presumed to have an availability of nine percent in January and six percent on an annual basis. It is slightly different from the value now used by the Svenska kraftnät in its annual power balance reports. There eleven per cent availability of wind power is estimated during the winter months. By 2020 this forecast assumes that four of the nuclear blocks (O1, O2, R1 and R2) are taken out of service.

ENTSO’s power balance forecasts study the concepts of RC and ARM. RC is the remaining capacity after the expenditure has been drawn out from the available capacity and the available consumption reduction has been added. ARM should mirror the production capacity that should be available in order to guarantee reliability of supply by unforeseen events in combination with higher consumption. If RC is larger than ARM, the power balance is considered to be good.

Throughout this ten-year period RC is assessed to be less than ARM during January and February. This means that the margins for unforeseen incidents are small. The assessment is, however, that there is sufficient import capacity to cover the need.

Development of power balance and delivery reliability is illustrated by the following maps from the ENTSO. Countries highlighted in orange have a situation where RC < ARM, that is, they either have a deficit in normal situation or may find it difficult to cope with unexpected events without the support of the import.

Cooperation within the ENTSO seeks to expand transmission capacity in order to improve reliability of supply. In spite of that, the maps show that the power balance deteriorates over the next ten years. The large expansion of intermittent production contributes to this course.

6.3 The need for regulation power

Considering the power balance in the power system, frequency is the same all over the synchronous AC system. The frequency variations affect the entire synchronous system.

The power system has a natural inertia to frequency changes due to the kinetic energy of synchronously connected machines. Over 95% of the mechanical kinetic energy of the power system is concentrated in the power generation turbines and generators. The kinetic energy (inertia mass) is very small compared to the energy produced in the system.

31. ENTSO-E Scenario Outlook and Adequacy Forecast (SO&AF) 2015.
32. Availability figures provided by ENTSO-E to make different countries calculate with the same references.
34. Remaining Capacity.
35. Adequacy Reference Margin.
A significant impact on the frequency takes place even at a moderate imbalance between the production in the turbines and the power output from generators. For example, if the generator power is one percent greater than the turbine gate-opening the rate will sink 0.1 Hz in three seconds in the synchronous system.

The power balance in a power system is the balance between the total turbine power and the overall power output of the generators. If these two powers are equal, the machines will run with constant frequency. In the grid in any moment the electric power output from the generators is equal to the load and losses.

How the power production system is to be run at a specific time, is scheduled on the basis of forecasts for consumption and production. Because the prognosis is associated with uncertainty, a certain percentage of the total production is reserved and always available in order to compensate for any forecast error.

However, it is not just forecast errors that may give rise to imbalances between production and consumption. Even disorders – which give rise to for example unexpected disconnection of production – may create imbalances that need to be handled with the help of reserved production capacity, known as reserves.

Two main types of reserves exist, both automatic reserves activated automatically on frequency deviations and, on the other hand, reserves which are activated manually by operators in Svenska kraftnät’s control rooms. The frequency-controlled automatic reserves are activated relative to the instantaneous frequency deviation from 50.0 Hertz and the reserves attempt to reset the frequency to 50.0 Hertz.

The automatic frequency-controlled reserves are divided into two parts. The first is the part designed to deal with normal imbalances arising for example stochastic variations in consumption and weather-dependent production – frequency-controlled normal operating reserve (FCR-N). The other is the part that is intended to manage sudden disconnection of production plants or HVDC transmissions from adjacent systems – frequency-controlled reserve of disturbance (FCR-D).

It is required for the Nordic power system that there should always be an automatic frequency-controlled normal operating reserve of 600 MW. The percentage of the automatic frequency-controlled normal operational reserve that each country shall contribute, is determined in proportion to the annual electricity consumption. Sweden’s share is currently about 245 MW. The corresponding requirements for the automatic frequency controlled disturbance reserve are equal to the size of the largest phased production unit minus 200 MW. The distribution between countries takes place in relation to the largest unit in each country. Sweden’s share is currently about 440 MW.

After activation of the automatic, frequency controlled reserves they need to be reset. This is done by manual activation of other production – primarily through allotment of bids in the regulation power market and, secondly, by starting of those gas turbines that make up the fast disturbance reserve. The production, which will reset the automatic reserves, shall be activated within 15 minutes of the call. The demand on Svenska kraftnät is that the rapid interference reserve shall be equivalent to the largest phased production source, at most about 1,450 MW (= Oskarshamn 3).

The production portfolios in Sweden and Europe are under rapid change and the trend is towards several, smaller

36. According to Kirchhoff’s law the sum of the currents in a point are zero.
production units. These are also widely distributed in the system, but often located in regional and local area networks. Historically, the uncertainty in the power balance has, in addition to fault incidents, been on the consumption side. As the weather-dependent production has expanded, mainly in the form of wind power, the uncertainty has also increased on the production side.

Available regulation resources are critical for a secure and effective way to integrate large volumes of wind power. Analyses indicate that it is primarily the need for manual regulation resources that increases as the proportion of wind power increases. An increased ability to use consumption as regulation resource will play an important role when the proportion of unpredictable production increases.

Limited transmission capacity poses a challenge for high wind power production when regulation bids become unavailable and production deviates significantly from the plan. Such situations may for example occur in SE4, when transmission from the north is limited by interface 4 and available regulation bids in the region are scarce.

By extending transmission capacity to the neighboring countries and removing internal bottlenecks, regulating resources may be used more flexibly and made available also for more remote needs. Even a greater opportunity for exchanging power between adjacent regions and countries would facilitate the handling of large amounts of wind power generation in the Nordic countries and Northern Europe.

Handling of large volumes of wind power requires continually updated wind forecasts and central monitoring of the production of wind power in real time. Real-time monitoring of wind power production is required for, among other things, being able to verify the wind forecasts and to monitor the imbalances.

It may, for example, be difficult to predict with high accuracy when a weather front reaches a certain area, but real-time monitoring of actual production presents opportunities to reconcile forecasts against the outcome on an ongoing basis. Accurate and updated forecasts are of great importance for Svenska kraftnät’s planning of the power system operation. They may be critical for making regulating resources with longer start-up time available.

6.4 Smart grids

Smart grid is an international concept and collective name for several different applications within the electricity supply, both when it comes to production and within transmission, distribution and consumption. It includes equipment, application of new legislation and solutions of problems that new technology makes possible.

It is not about a new grid to be built to replace the existing; the concept reflects those different expectations that exist to the future electricity system. They span from customer solutions for meters and intelligent household machines, to intercontinental transmission networks that utilise higher voltage levels than today’s in order to transmit large quantities of renewable electricity energy.

Svenska kraftnät continuously evaluates whether new technology may be used when measures shall be applied to the core network. Svenska kraftnät’s view of the concept smart grids is that this is the most intelligent, effective and economic way of using new technology to develop the present electricity system in order to meet the requirements for a long-term sustainable energy supply. In a core network perspective, it is about using new technology in areas such as balance control, transmission capacity, system stabilization, resilience to, and handling of disturbances, and control and monitoring.

An example of new technology that is entering into transmission networks, is integrated HVDC-systems that require sophisticated monitoring and control system in order to interact in an optimum manner with the AC network. Svenska kraftnät is installing such a system integrated in the South West Link.

Another example is what goes under the name WAMS (Wide Area Measurement System) that allows collection of large quantities of data for analysis of incidents in the power system. In the future it even gives possibilities for controlling components on the basis of these incidents in order to prevent disturbances in the electricity supply.

In those new stations being built now by Svenska kraftnät, Phasor Measurement Units (PMU) are being installed. Phase angle measuring units with accurate time stamps on the information, allow these types of monitoring and control systems. Already for some time Svenska kraftnät has been using system protection, by means of communication system that link components during particular incidents either in order to increase operational security or to increase the capacity in the power system. Long term energy storage may become a feasible application also at transmission level. Today, however, the technology is not developed for handling sufficiently large energy quantities.

Small-scale production (smaller than ten MW) must be evaluated separately by the operational balance service, since it is not measured or included in the balance-responsibles’ production plans. With increased possibilities for smart grids through new and improved technology plus reductions in the legal requirements on network concessions, small-scale electricity generation is expected to increase. It means a still greater challenge for the operational production.

A way to increase the potential for controlling the small-scale production and moreover to increase the amount of regulating potential, is to lower today’s requirement of ten MW per proposal in the regulating power market for SE1, SE2 and SE3 to five MW. There are, however, some start-up obstacles for the small operators in question. Such as administration and systems required to report plans, proposals, measurement etc. Such obstacles in the regulated energy market might be cleared by so-called aggregators that coordinate the small-scale production to larger units.
7. THE INVESTMENT PLAN

The initial chapters show that Svenska kraftnät in its planning has to relate to a very complex operating environment. Energy and climate policy provides strong incentives for extensive investment in new transmission capacity but there is also a need for reinvestment in the high voltage transmission network, which is older in Sweden than in many other countries.

The environmental factors that affect network planning are also changing rapidly. Various measures taken by producers and network owners in Sweden – but also in neighbouring countries, affect the system flows and conditions for Svenska kraftnät’s investments. In this respect Svenska kraftnät also often plays a reactive role.

In order to achieve the political objectives, there is a wide consensus on the need for greater investment in network infrastructure and an increased interconnection between the EU member states. This in turn creates a need to analyse and identify the steps required to strengthen the National Grid in areas where new internal constraints may arise.

The Swedish energy policy of course exerts a large influence. The electricity certificate system has led to a very rapid expansion of renewable electricity production, which has to be delivered to the customers. New access points need to be built and capacity-enhancing measures taken.

A rapidly increasing share of weather-dependent electricity generation – together with successive phase out of predictable power generation in, among other things our nuclear power stations – leads to a series of systems-related challenges. Even these challenges must to some extent be met with a variety of investments in National Grid area facilities.

This chapter reviews the investments that currently are considered to become relevant and require resources during the ten-year period 2016-2025. The projects included in the plan are the current best estimate. New projects will gradually be added while others are cancelled or adjusted in time and scope. This is an inevitable consequence of the many parameters that influence the conditions and drivers for the investment work.

There is also an ongoing development work concerning the conditions for the investment plan’s assumptions about disruption risks, resource requirements etc. More generally, the closer a project is to start operation, i.e. the further it has come in the implementation process, the more precise is the information set out in the plan.

The investments are presented per region and classified according to the three categories current, planned or under consideration.

**Current projects**
A project is classified as current when the Svenska kraftnät’s Board of Directors has decided to implement the investment. Current projects may be in different stages. These stages follow the same order in all projects. A project that is in a later phase has consequently completed the previous stages. The phases are:

- **Decided** Decision has been made either to initiate design (choice of approach) or to carry out the project (investment decision).
- **Concession** Efforts to apply for concession are in progress.
- **Procurement** The project has been granted a concession and effort is underway with procurement of various construction works.
- **Construction** The project has been contracted and construction is in progress.

Many current projects do not need new concession and for these this stage is consequently not applicable. Current projects may in exceptional cases be cancelled but adjustments in such projects normally refer to regular changes in schedules or cost estimations, often as a result of changes in priorities, delays or improved information about costs.

**Planned projects**
A project is classified as planned when it is between investigation and decision. At this time more thorough pre-studies are made to provide a better basis for schedules and cost estimations. In projects involving external parties, work is going on to establish various agreements.

Sometimes planned projects are not realised as intended. This typically applies to projects that have their driver in assigning external parties. In these cases Svenska kraftnät does not control the entire decision-making process, but implementation could ultimately depend on whether, for
example, a wind power builder gets funding for his project and is able to sign the connection agreement with Svenska kraftnät.

**Under consideration**

A project is classified as under consideration when investigation is still going on about conditions for the investment to be made. There are also projects where the investigation has not yet started but where a clear need has been identified to initiate actions under the ten-year period. Most concern reinvestment in plants where the technical life span is expected to be reached during the ten-year period. As an example may also be mentioned those wind power connections found near the end of the plan’s time span and in which there are not yet any definite connection requests.

Svenska kraftnät assumes that a number of such projects will be implemented, even beyond the planning horizon of three to four years that these projects typically have. The group “under consideration” has the biggest uncertainty about whether and when the projects will be implemented.

In many cases, future connection needs have not been made definite, so that specific station projects have also not been identified. Instead, they are posted in the plan with a certain number of stations per region. The number is based on the amount of renewable electricity production scheduled within the respective region. They should therefore be seen as an anticipated volume of projects. They are likely to change with regard to time, scope and location. And if connection can be made to existing National Grid stations, they may instead be renewed ahead of time. Cost estimates and time schedules are rough sketches.

**Explanation of tables**

Tables for each region and phase include the following information.

- **No** Serial number as displayed in the map for each region.
- **Phase** Phases decided, concession, procurement and construction stage according to the description above. This applies to current projects.
- **Start of feasibility study** Date of decision for a technical feasibility study that describes the scope for the investment and sets the framework for its implementation.
- **Decision date** Estimated date for deciding on whether to carry out the investment.
- **Commissioning** Planned time for putting the plant into operation. If made in stages, the date gives the time for the final commissioning.
- **Cost** The estimated cost of the investment. The uncertainty of the estimate is larger in early project stages.
- **Motive** The project’s main driving force (cf. Chapter 4).
7.1 Luleå region (SE1)

7.1.1 About SE1

Region SE1 includes part of Norrbotten and Västerbotten Counties. SE1 is sparsely populated. The larger cities of Kalix, Haparanda, Luleå, Piteå, and Skellefteå account for most of the region’s consumption. It is also high in Kiruna municipality, where a large part of the mining industry is located.

Interface 1 is made up of the region’s southern border with region Sundsvall (SE2), and goes from the coast between Skellefteå and Umeå towards the north-west, further inland following the county border between Norrbotten and Västerbotten until the Norwegian border. Interface 1 is made up by four 400 kV transmission lines. Maximum transmission capacity in the interface is 3,300 MW.

In addition to the 400 kV network in SE1 there is also a 130 kV network along the Lule River. This network runs across Sweden parallel to the National Grid from the Norwegian to the Finnish borders.

Four foreign connections currently come out from SE1. There are two 400 kV lines and a 220 kV line to Finland and a 400 kV line to Norway. The 220-kV line to Finland will be phased out in 2016.

As shown in Table 5, electricity generation in SE1 mainly comes from hydroelectric power. The largest power plants are located in Lule River and Skellefte River. The region’s installed hydroelectric power is barely 5,200 MW and the production during a normal year about 19 TWh. Installed wind power in SE1 is just under 500 MW.

The area’s power and energy balance is good and SE1 has a large surplus (cf. Table 5). In 2014 this electricity surplus was 10 TWh. It is mainly transmitted via the National Grid southwards to the consumption centres in southern Sweden and exported to Finland.

This need for north-south transmission is reflected very clearly in the structure of the National Grid. Towards the end of the decade the area’s energy surplus is expected to increase slightly as a result of additional wind power. A certain change in the energy flow is also expected. Compared to today’s situation, the surplus is to a greater extent expected to go southwards in Sweden rather than abroad.

The future need for measures in SE1 is strongly linked to the increasing amount of renewable power generation expected in northern Sweden, Norway and Finland. This leads to an increased need for transfer of the growing surplus in SE1, and also a higher exploitation of the regulation capability that exists in the area’s hydroelectric power. Svenska kraftnät currently has requests for connection of more than 5,000 MW of wind power in SE1.

In the longer term Svenska kraftnät needs to renew the lines in the region. In SE1 several lines are more than 50 years old with need of repair.

Seven line stretches in the 400 kV network are planned to be upgraded and change of top wires are planned on at least four lines. During the ten-year period, renewal will begin on 1,000 kilometres of 400 kV lines in SE1.

The reinvestments planned in the stations’ facilities are, above all, for the renewal of eight stations. In addition a large number of changes are also planned in individual components of primary equipment and control facilities.

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**TABLE 5 POWER AND ENERGY STATUS IN SE1 2014 AND 2025.**

<table>
<thead>
<tr>
<th>POWER TYPE</th>
<th>PRODUCTION 2014 (TWh)</th>
<th>PRODUCTION 2025 (TWh)</th>
<th>INSTALLED POWER 2014 (MW)</th>
<th>INSTALLED POWER 2025 (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro power</td>
<td>18</td>
<td>20</td>
<td>5,200</td>
<td>5,200</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wind power</td>
<td>1</td>
<td>3</td>
<td>500</td>
<td>1,300</td>
</tr>
<tr>
<td>Combined heat and power</td>
<td>1</td>
<td>1</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Solar power</td>
<td>N/E</td>
<td>0</td>
<td>N/E</td>
<td>0</td>
</tr>
<tr>
<td>Condensate power and gas</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL PRODUCTION</strong></td>
<td><strong>20</strong></td>
<td><strong>24</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption</td>
<td>-10</td>
<td>-11</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BALANCE</strong></td>
<td>10</td>
<td>13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The figures for installed power in 2014 are rounded off and taken from Elåret 2014, Svensk Energi. They are allocated across regions based on the Svenska kraftnät’s measured values. The values for 2025 are the Svenska kraftnät’s assumptions.
7.1.2 Project overview SE1

Figure 16. SE1 - All projects.
7.1.3 Current and planned

Today's 220 kV line between Ossauskoski in Finland and Kalix will be phased out in 2016. The line is currently supplying Kalix, which means that a new feeder-point to Kalix is required. This has been solved by a new National Grid station, Djuptjärn, that was put into operation in 2015 on the 400-kV line between Svartbyn and Keminmaa in order to connect to the 130-kV network in Kalix.

Svenska kraftnät has built a new 400 kV station, Råbäcken, on the line between Svartbyn and Stornorrfors. This has been done to allow for the connection of the first stage of the large wind farm project Markbygden. Now the next stage of Markbygden is scheduled for about 1,300 MW, which means that an additional National Grid station, Trolltjärn, will be built in the 400 kV line between Letsi and Betåsen. Even some line measures are being considered for Markbygden.

There is currently a station renewal going on in SE1. Station Porjus is replaced with one in a new location some distance from the original station, which has been named Porjusberget. In addition, a station renewal is planned in HarSprånget.

In connection with the Porjusberget station renewal, planned interruptions are conducted for work on the lines in the area. These actions bring about increased operational and personal security. Other major measures in SE1 are to renew opto connections in order to ensure communication between stations.

7.1.4 Under consideration

More station projects are under consideration for connection of wind power and for capacity reasons. Construction is supposed to begin on two more stations during the ten-year period for connection of new production or network. These include a third phase of the wind farm Markbygden.

Planning for status improvements of four lines is so well advanced that technical feasibility studies can be launched over the next few years. Feasibility studies are to be done for three station renewals in the next few years and three more a few years into the 2020s. They include Ritsem, Letsi, Ligga, Svartbyn, Vargfors and Messaure.

The capacity between Sweden and Finland

As stated in Perspective plan 2025 Svenska kraftnät and Fingrid are now jointly analysing conditions for a third 400 kV line between Sweden and Finland. The need depends on the development of production and networks in the two countries.

In Perspective plan 2025 the line is mainly motivated by greater reliability of supply on the Finnish side, increased opportunities for exploiting regulation resources on both sides of the border, as well as sufficient transmission capacity to maintain voltage stability in the event of a failure in the coming new nuclear reactor in Olkiluoto.

Since then, the situation has changed in Finland. Olkiluoto 3 has been postponed by several years, imports from Russia.
have been discontinued and about 1,000 MW condensate production has been closed. In the past year this has caused the Finnish electricity price to be significantly higher than the price of electricity in the other Nordic countries. Improved integration of markets would even out electricity prices between Finland and the other Nordic countries and this seems today to be the strongest driver for the new line.

The need for a new line is also influenced by the fact that new nuclear power is planned in Pyhäjoki in Northern Finland. The measures taken in Finland to reduce transmission limitations in the Finnish interface P1 also influence the benefits of a new line.

Today, a new line would be used mainly for flows from Sweden to Finland. An investment that should be exploited for several decades, however, must give Nordic advantage also under other operational conditions. The conclusion from Perspective Plan 2025 that the Swedish internal interfaces may need reinforcement before a new line to Finland is put into operation, therefore essentially remains firm.

The third AC line has long been a desire of Fingrid and on Finnish initiative it has been included in several planning documents. It should be emphasised that the line never has represented a “sharp” project in any network investment plan. When the results of the Swedish-Finnish analysis appear, Svenska kraftnät will begin its feasibility study. That is estimated to be during 2016. If a third AC line is subsequently decided, it can be operational by 2025 at the earliest, due to the licensing processes.

### TABLE 8. SE1 PROJECTS UNDER CONSIDERATION

<table>
<thead>
<tr>
<th>NO</th>
<th>PROJECT</th>
<th>FEASIBILITY STUDY START</th>
<th>DECISION</th>
<th>OPERATION</th>
<th>COST (MSEK)</th>
<th>MOTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>075</td>
<td>Serial compensation interface 1</td>
<td>1/2017</td>
<td>1/2018</td>
<td>2020-2025</td>
<td>600</td>
<td>Market integration</td>
</tr>
<tr>
<td></td>
<td>Markbygden phase 3</td>
<td>1/2016</td>
<td>1/2017</td>
<td>2024</td>
<td>370</td>
<td>Connection of production &amp; network</td>
</tr>
<tr>
<td>072</td>
<td>Finland 3rd AC line</td>
<td>2/2016</td>
<td>1/2018</td>
<td>2025-2028</td>
<td>850</td>
<td>Market integration</td>
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<td></td>
<td>New wind power connection</td>
<td>running</td>
<td>running</td>
<td>2020-2028</td>
<td>160</td>
<td>Connection of production and network</td>
</tr>
<tr>
<td></td>
<td>2020-2028 SE1</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>752</td>
<td>Ritsen PK51 station renewal</td>
<td>1/2016</td>
<td>1/2017</td>
<td>2020</td>
<td>85</td>
<td>Reinvestment</td>
</tr>
<tr>
<td>190</td>
<td>Letsi PK46 station renewal</td>
<td>1/2017</td>
<td>1/2018</td>
<td>2021</td>
<td>125</td>
<td>Reinvestment</td>
</tr>
<tr>
<td>302</td>
<td>Liggå PK3 station renewal</td>
<td>1/2017</td>
<td>1/2018</td>
<td>2021</td>
<td>120</td>
<td>Reinvestment</td>
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<tr>
<td>517</td>
<td>Liggå-Messaure UL6 S1 opto</td>
<td>2/2017</td>
<td>1/2018</td>
<td>2021</td>
<td>5</td>
<td>Reinvestment</td>
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<tr>
<td>599</td>
<td>Svarby-Finnish border UL21 status</td>
<td>2/2017</td>
<td>1/2018</td>
<td>2022</td>
<td>5</td>
<td>Reinvestment</td>
</tr>
<tr>
<td></td>
<td>measures</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>754</td>
<td>Svarby UT42 station renewal</td>
<td>2021</td>
<td>2022</td>
<td>2025</td>
<td>105</td>
<td>Reinvestment</td>
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<tr>
<td>977</td>
<td>Letsi-Finnish border UL8 S1-4 status</td>
<td>2023</td>
<td>2024</td>
<td>2026</td>
<td>10</td>
<td>Reinvestment</td>
</tr>
<tr>
<td>248</td>
<td>NK25-Vargfors station renewal</td>
<td>2023</td>
<td>2024</td>
<td>2027</td>
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<td>Reinvestment</td>
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<td>133</td>
<td>PK4-Messaure station renewal</td>
<td>2024</td>
<td>2025</td>
<td>2028</td>
<td>135</td>
<td>Reinvestment</td>
</tr>
</tbody>
</table>

### Capacity over interface 1

The assessment in Perspective plan 2025 for a cost-effective way to increase capacity over interface 1, was to serially compensate the four 400 kV transmission lines in the interface. This has now been investigated in more detail. In doing so, serial compensation in interface 1 has been analysed together with shunt compensation in interface 2, upgrading of existing serial compensation in interface 2, internal reinforcements in SE2, and a new line over interface 2.

These network analyses reveal that a serial compensation of interface 1 can increase capacity by more than a third of today’s capacity - from 3,300 to 4,500 MW — but it is doubtful whether the advantages suffice to justify investment.

The analyses indicate that the measures on interface 2 should be given priority (cf. also section 7.2.4). A serial compensation of interface 1 may, however, provide some positive impact on the capacity of interface 2. This will be evaluated in relation to the alternate capacity-measures for interface 2.

In summary, final decision on serial compensation measures in interface 1 should in any case wait until the Finland study is available in the second half of the year 2016.

### 7.2 Sundsvall region (SE2)

#### 7.2.1 About SE2

Region SE2 includes part of Dalarna County and Västernorrland, Jämtland and Gävleborg Counties. As in SE1, many large centres of consumption are situated along
the coast. These include Umeå, Örnsköldsvik, Härnösand, and Sundsvall. In addition there are the towns Östersund and Sollefteå in the interior.

Interface 2 constitutes the border southwards towards Stockholm region (SE3). Interface 2 runs along a line from Gävle to the north-west through the north part of Dalarna. Interface 2 consists of eight serially compensated 400 kV lines and three 220 kV lines. The maximum transmission capacity of the interface is 7,300 MW.

From SE2 two external links go to Norway. One is a 400 kV line from Järpströmmen in the neighbourhood of Åre to Nea and the other an older 220 kV connection from Ajaure in Västerbotten to Nedre Rössåga.

SE2 has a widespread 220 kV network built to transfer electricity from hydropower in central Norrland rivers to regional areas of consumption and transformer points to the overlying 400 kV network. In addition, there are local regional networks of 130 kV and 70 kV parallel to the National Grid. They are largely connected to 220 kV stations.

As shown in Table 6 electricity generation in SE2 mostly come from hydroelectric power. Large power plants are found in the Ume River, the Ångerman River and the river Indalsälven. The installed power in hydropower plants is about 8,000 MW and production during a normal year amounts to about 36 TWh. Installed wind power is just below 1,500 MW.

The area’s power and energy balance is good and SE2 has large surpluses (cf. Table 6). In 2014 electricity surplus was 21 TWh. The surplus from the area is transmitted mainly via the National Grid to the south to the consumption centres in southern Sweden. This causes the 400 kV network in SE2 to have a distinctive north-south structure.

Even SE2 is expected to have an increasing energy surplus until 2025. The north-south flow will increase partly by the surplus transmitted from SE1; on the other hand, more wind power-generation in SE2. The bulk of the surplus flows southwards over interface 2 to SE3.

The need for new investment in SE2 is strongly coupled to the very large amount of renewable electricity production which is expected to be added in the region. Today there are requests for connecting about 12,000 MW of new wind power in SE2. The increase in production that is coming will load the transmission in the 400 kV network southwards towards SE3 as well as the relatively weak 220 kV network, which today collects electricity production from hydropower.

The latter is heavily congested, at times also having problems with high voltages. The consequence is that parts of the 220 kV network has no spare capacity for new connections. Even today counter trade occurs in operational conditions with large surpluses in order to prevent the grid from being overloaded. It is therefore important to build new transformer points to increase the ability for connecting more wind power to the 220 kV network. The capacity for transmission southwards through interface 2 must also be increased.

Since there are large amounts of hydropower in the area, variations in the flow will also increase when hydropower regulating ability increasingly must be called upon to even out the weather-dependent production of electricity. In the long term, 400 kV lines in the region have to be gradually renewed and such a need already exists in the 220 kV network.

In SE2 there are several lines that have passed the age of 70 years. Renewal of the first of the eight 400 kV lines over interface 2, as shown in section 7.2.4 will be started as soon as possible. For the other lines, a renewal can be initiated only at the end of the plan period.

Further improvement measures are planned for about a dozen line stretches in the 400 kV network and on some 30 line sections in the 220 kV network. In addition to upgrading, replacement of the top lines alternatively opto connections is planned on a dozen lines. In total refurbishment measures are planned on about 3,400 km in the line network in SE2.

The reinvestments that are planned in the region’s station facilities are, above all, about renewal of the old stations from the twenties. In addition, a large number of changes in individual components of primary installations and control equipment are also planned.

**TABLE 9. POWER AND ENERGY STATUS IN SE2 2014 AND 2025.**

<table>
<thead>
<tr>
<th>POWERTYPE</th>
<th>PRODUCTION 2014 (TWh)</th>
<th>PRODUCTION 2025 (TWh)</th>
<th>INSTALLED POWER 2014 (MW)</th>
<th>INSTALLED POWER 2025 (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro power</td>
<td>33.5</td>
<td>37</td>
<td>8,000</td>
<td>8,000</td>
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<tr>
<td>Nuclear power</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wind power</td>
<td>2.5</td>
<td>9</td>
<td>1,450</td>
<td>4,100</td>
</tr>
<tr>
<td>Combined heat and power</td>
<td>2</td>
<td>2</td>
<td>600</td>
<td>700</td>
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<tr>
<td>Solar power</td>
<td>N/E</td>
<td>0</td>
<td>N/E</td>
<td>0</td>
</tr>
<tr>
<td>Condensate power and gas turbines</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td><strong>TOTAL PRODUCTION</strong></td>
<td><strong>38</strong></td>
<td><strong>48</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption</td>
<td>-17</td>
<td>-18</td>
<td></td>
<td></td>
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</table>

The figures for installed power in 2014 are rounded off and taken from Elåret 2014, Svensk Energi. They are allocated to regions based on the Svenska kraftnät’s measured values. The values for 2025 are the Svenska kraftnät’s estimates.
7.2.2 Project overview SE2

Figure 17. SE2 – Current and planned projects.
Figure 18. SE2 – Projects under consideration.
7.2.3 Current and planned

A new station Torpberget will collect parts of the wind power planned in SE2. The station is to be built on the line between Storfinnforsen and Lindbacka in Gävleborg County.

A new systems transformer between the 220 kV and 400 kV networks will be built in Hjälta in Västernorrland. The project also includes the construction of a new 220 kV station, Helgum, which connects to the net via a new line. This is done to ease the load on today’s heavily loaded 220 kV network and enable the connection of additional production.

A new line is being built between Storfinnforsen and Långbjörn. It is required to increase operational reliability and ensure that production does not become trapped by a single failure in the National Grid. Today the line Långbjörn – Kilforsen is the only 400 kV line connected to Långbjörn. This means that interruptions impose limitations for the production for affected plants. In the event of line failure, production facilities are now automatically disconnected in order to maintain reliability.

The 62 km long line between Storfinnforsen and Midskog is also being renewed. The stretch is part of the more than 60-year-old Harsprångs-line that runs down to Hallsberg.

Currently, the production of wind power surrounding Storfinnforsen has to be restricted during maintenance and faults in the grid to avoid line overload. Continued wind power development in SE1 and SE2 will involve production being

<table>
<thead>
<tr>
<th>NO</th>
<th>CURRENT PROJECTS SE2</th>
<th>PHASE</th>
<th>OPERATION</th>
<th>COST [MSEK]</th>
<th>MOTIVE</th>
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<td>508</td>
<td>Hjälta area-new 400/220 kV transformer-station measures</td>
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<td>Connection of production &amp; network</td>
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<td>Långbjörn-Storfinnforsen new 400 kV line</td>
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<td>550</td>
<td>Storfinnforsen-Forsse AL5 S1, S2-3, S8 status measures</td>
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<td>Linåsen-Djumro CL22 S1-2 top line change</td>
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<tr>
<td>512</td>
<td>Midskog-Mörsk KL8 S1, S2 status measures</td>
<td>Decided</td>
<td>2017</td>
<td>5</td>
<td>Reinvestment</td>
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<td>Korsellbrännaborder AL2 S9</td>
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<tr>
<td>554</td>
<td>Moforsen border -Forsmo AL6 S1 status measures</td>
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<td>10</td>
<td>Reinvestment</td>
</tr>
<tr>
<td>562</td>
<td>Ajaure-border Gejmårn AL7 S3 status measures</td>
<td>Decided</td>
<td>2017</td>
<td>5</td>
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</tr>
<tr>
<td>584</td>
<td>Hölleforsen-Järviussle border RL8 S2 status measures</td>
<td>Decided</td>
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<tr>
<td>410</td>
<td>Krångede-Hornadal reconstruction</td>
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<td>2018</td>
<td>100</td>
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<tr>
<td>367</td>
<td>Storfinnforsen-Torpshammar RL2 S1 top line exchange</td>
<td>Decided</td>
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<tr>
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<td>430</td>
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<tr>
<td>526</td>
<td>Tuggen-Hjälta UL7 S2 status measures</td>
<td>Decided</td>
<td>2018</td>
<td>15</td>
<td>Reinvestment</td>
</tr>
</tbody>
</table>
trapped even during normal operation. Therefore, line capacity will be increased in connection with the renewal.

By station renewals, planned interruptions are even used to repair the lines that are connected to the stations in order to, among other things, increase operational and personal safety.

The region SE2 has the greatest number of inquiries and applications for the connection of wind power to the National Grid. The overall effect in requests to Svenska kraftnät currently amounts to more than 12,000 MW. Many of the applications are of a magnitude that requires the connections to be made to the 400 kV network.

New production is primarily connected to existing National Grid stations. Thus, new connections are planned to 400 kV stations Storfinnforsen, Rätan, Grundfors and Betåsen. In this context stations in Rätan and Grundfors are also renewed.

In the 220 kV network wind power connections are planned to Laforsen and Midskog. At the same time, the station in Midskog is renewed and relocated slightly to the south.

There are also plans to build brand new 400 kV station for connection of wind power in SE2. These include Norrtjärn to be built in Västerbotten on the line between Tuggen and Hjälta, stations Olingan and Rissna in Jämtland, Nässe in Västernorrland and Gäddtjärn and in Dalarna.

Currently, six lines are scheduled for renewal, but in the next year, further line measures will reach the technical feasibility study phase.

### PLANNED PROJECTS SE2

<table>
<thead>
<tr>
<th>NO</th>
<th>PLANNED</th>
<th>DECISION</th>
<th>OPERATION</th>
<th>COST (M SEK)</th>
<th>MOTIVE</th>
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<tr>
<td>402</td>
<td>Norrtjärn new 400/130 kV station connection UL7 S2</td>
<td>1/2016</td>
<td>2018</td>
<td>115</td>
<td>Connection of production &amp; network</td>
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<tr>
<td>511</td>
<td>Storfinnforsen CT90 an circuit wind power</td>
<td>1/2016</td>
<td>2017</td>
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<tr>
<td>774</td>
<td>Laforsen RT72 wind power connection</td>
<td>1/2016</td>
<td>2017</td>
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<tr>
<td>773</td>
<td>Betåsen UT67 wind power connection</td>
<td>1/2016</td>
<td>2018</td>
<td>20</td>
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</tr>
<tr>
<td>766</td>
<td>Nässe new 400 kV station connection CL26 S3-4</td>
<td>1/2016</td>
<td>2019</td>
<td>125</td>
<td>Connection of production &amp; network</td>
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<td>715</td>
<td>Olingan new 400 kV station</td>
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<td>95</td>
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<td>765, 954</td>
<td>Gäddtjärn new 400 kV station cor. CL4 S1-3 and renewal EK4 Djurmo</td>
<td>2/2016</td>
<td>2019</td>
<td>230</td>
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<td>Rissna new 400 kV station connection CL1 S2-3</td>
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<td>2020</td>
<td>160</td>
<td>Connection of production &amp; network</td>
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<td>351, 825</td>
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<td>1/2016</td>
<td>2019</td>
<td>150</td>
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</tr>
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<td>987</td>
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<td>2/2016</td>
<td>2020</td>
<td>160</td>
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<tr>
<td>930</td>
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<td>567</td>
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<td>2020</td>
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<td>527</td>
<td>Nysäter-Vittersjö CL3 S2 status measures</td>
<td>1/2016</td>
<td>2023</td>
<td>15</td>
<td>Reinvestment</td>
</tr>
</tbody>
</table>
7.2.4 Under consideration

Two new stations, Tovåsen and Hammarstrand, are supposed to be built in Jämtland. The motivating factor is, in particular, the increased production in the area. In addition, connections to the 400 kV station Tuggen and Moliden are considered, and also to the 220 kV-stations Lasele, Åsele and Hällby. The projects are in the early stages and there is real uncertainty about which of them will be implemented.

In addition, it is assumed that another ten stations, motivated by the future connection of new production or networks, will be started in SE2 during the ten-year period. Today’s feed to the Jämtland area via a 400 kV line and a 220 kV line from Midskog, is sensitive to disturbances. Parts of the installed production and the line to Norway are currently disconnected in the event of failure of the 400 kV line. To be able to deal with this and to allow for the connection of new production, network reinforcement is being investigated. A possible solution might be to upgrade the current 220 kV line to 400 kV.

The SE2 National Grid is heavily loaded, making it increasingly difficult to schedule extended cut-offs. The interruptions affect electricity market and the regional division clarifies this influence to a greater extent than before.

In future scenarios, even the internal network within SE2 exhibits bottlenecks, therefore an investigation has been started to review the reinforcements required.

Four station renewals are planned for feasibility studies over the next few years. Two more start a few years into the 2020s. They include Kilforsen, Stornorrfors, Nysäter and Moliden. In addition, feasibility studies are planned for 15 station renewals, four in the 400 kV network and the rest in the 220 kV network.

The planning of status-improving measures and renewal of the lines Ånge – Laforsen and Laforsen – Hofors – Finnsläten is so well advanced that technical feasibility studies can be launched over the next two years.

This will be followed by several more considerable measures to be implemented. Their dates are yet to be fixed, because there are several full renewals to be initiated, which will affect the time plans. In total about 40 renewals with a reinvestment volume of about 1,500 million are considered in SE2.

The oldest lines, consequently those with the greatest need of renewal, are the 220 kV transmission lines in Hällsingland.

Increased capacity from Norrland over interface 2 to the middle of Sweden

In Perspective plan 2025, Svenska kraftnät indicated that the capacity on interface 2 requires significant increase. Shunt compensation of the interface lines was announced but also a brand new north-south 400 kV line. One of the reasons for the new line was the need to create a certain excess capacity to allow for the subsequent reinvestments that will have to be made in the eight 400 kV lines that now go to SE3.

Reinforcements will be made now to increase capacity between SE2 and SE3. This need is underlined by the early decommissioning of the nuclear power in SE3, which has been decided, and which will reduce the capacity on interface 2 with 700 MW from the current 7,300 MW to 6,600 MW.

The first measures to be implemented are to increase the reactive support, among other things, by installing shunt compensation in both SE2 and SE3. In addition, all eight serial compensation installations on the interface 2-lines will be renewed. This takes place gradually by modernization of stations on a schedule between 2017 and 2025.

Together with other internal reinforcements in SE2 and commissioning of SydVästlänken and NordBalt, the planned measures will increase the capacity through the interface to at least 7,800 MW. Preliminary studies indicate that the increase even could be much higher.

An entirely new north-south line, meaning a ninth connection across interface 2 is on this background not required for pure capacity reasons. The need remains, however, gradually to start renewal of the eight interface lines, which are old. This cannot be done with lines in operation and to have long interruptions will not be acceptable.

The only practical and realistic way of renewing an interface line is to build a new line in parallel with the old, which can then be torn down. Since the new line will have larger cross-section, the transmission capacity on interface 2 will gradually increase further as the interface lines are renewed.

Svenska kraftnät will therefore urgently commence the work to decide on which of the existing wiring stretches the first new 400 kV line shall be built. Subsequently the planning work may begin.
<table>
<thead>
<tr>
<th>NO</th>
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<th>DECISION</th>
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<td>2020</td>
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<td>2024</td>
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CONTINUE: PROJECTS UNDER CONSIDERATION, SE2

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7.3 Stockholm Region (SE3)

7.3.1 About SE3

Region SE3 covers most of central Sweden. It includes Stockholm, Uppsala, Västmanland, Örebro, Södermanland, Östergötland, Värmland, Gotland and Västra Götaland counties and parts of Dalarna, Gävleborg, Halland, Jönköping and Kalmar counties. SE3 has eight of the country’s ten largest cities – Stockholm, Göteborg, Uppsala, Västerås, Örebro, Linköping, Jönköping, and Norrköping. All three Swedish nuclear power plants are also located in SE3.

Interface 4 separates SE3 and SE4. It runs from just south of Oskarshamn on the eastern coast to the south of Varberg on the west coast. The interface is made up of five 400 kV transmission lines. There are also regional 130 kV networks parallel to the National Grid. The regional networks’ power transport is included in the capacity of interface 4. Interface 4 is that interface in the National Grid where flows most frequently hit the capacity ceiling. The maximum transmission capacity of the interface is 5,300 MW.

Also included in SE3 is the so-called west-coast interface, which can be limiting in periods when electricity is transmitted northwards on the west-coast lines to Norway. The power passing through the west-coast interface is determined mainly by exports to NO1 over the Hasle-interface, by the output of the four nuclear blocks in Ringhals and by imports from Denmark.

The two DC links Fenno-Skan 1 and 2 to Finland start from SE3, as well as two AC power connections over the so-called Hasle-interface to Norway (NO1), and the two DC links Konti-Skan 1 and 2 to Jutland (DK1). In addition to this, Ellevio is partner in a 130 kV AC connection Charlottenberg – Eidskog, included in the interconnection capacity between the SE3 and NO1.

As shown in Table 13, three quarters of the electricity production in SE3 comes from the three nuclear power plants in Forsmark, Oskarshamn and Ringhals. Nuclear energy’s installed power is approximately 9,500 MW. The installed power of the hydroelectric stations is about 2,600 MW and installed wind power is about 2,000 MW.

In total SE3 accounts for more than 60 percent of the country’s electricity use. Despite the fact that all Swedish nuclear power is produced in SE3, production and consumption of electrical energy balance evenly in the area. Forward towards 2025, however, an increasing deficit arises when the oldest nuclear power blocks are phased out.

The deficit at that time is estimated to around 12 TWh (cf. Table 13). It is covered mostly by a planned increase in the transmission from SE2. Some redistribution from export to the neighbouring countries towards increased transmission to SE4, is also expected to take place in SE3.

Requests for connection of new wind power in SE3 are modest compared to the figures in the SE1 and SE2. They currently amount to approximately 700 MW. Major measures in SE3 are made by the need to ensure the Metropolitan area long-term electricity supply and to remedy the limitations of transmission capacity in southern Sweden (SE4).

The extensive measures previously considered in order to allow additional power input from nuclear power plants, have in large part been cancelled, as several previously planned power increases will not be carried through.

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<th>PRODUCTION 2014 (TWh)</th>
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<th>INSTALLED POWER 2025 (MW)</th>
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<tr>
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<td>BALANCE</td>
<td>1</td>
<td>-12</td>
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Table 7. The figures for installed power in 2014 are rounded off and taken from Elåret 2014, Svensk Energi. They have been allocated over the regions based on Svenska kraftnät’s measurements. The values for 2025 are the Svenska kraftnät’s assumptions.
7.3.2 Project overview SE3

Figure 19. SE3 - Ongoing and planned projects.
Figure 20. SE3 - Projects under consideration.
7.3.3 Current and planned

There are several large-scale projects in SE3 either going on or planned. The largest project is Stockholm’s Electricity, which aims to secure the Metropolitan electricity supply long-term. Other major projects relate to increased transmission capacity to the south of Sweden and to Gotland.

**Stockholm’s Electricity and Storstockholm Väst**

Until 2025 Svenska kraftnät will invest nearly six thousand million SEK in Stockholm’s Electricity. The program includes some 50 subprojects and involves in addition to Svenska kraftnät even network owners Vattenfall Eldistribution and Ellevio (formerly Fortum Distribution). It involves 21 municipalities in Stockholm County.

The background is that the Government in 2004 directed the Svenska kraftnät to develop a proposal for the design of the future grid in the Stockholm region. Together with the regional network owners Svenska kraftnät prepared a new structure to meet future requirements for transmission capacity, availability, reliability and a good environment. The proposals were presented in an interim report in 2005 and a final report in 2008.

The new network structure means that large parts of today’s relatively small-meshed 220 kV networks will be dismantled. In other parts of the network the voltage level will be increased from 220 kV to 400 kV. A 400 kV cable – CityLink – is placed under the city centre in a drilled tunnel.

The new network structure allows approximately 150 km overhead power lines to be taken down. Municipalities and other landowners share financing with Stockholm’s Electricity in relation to the value of the land thus freed up for other use.

A major challenge is the increased generation of reactive power that the new cables bring about. It may therefore be necessary to install controllable shunt reactors to be able to regulate the voltage under various load conditions in the electric power system.

Power consumption needs have grown faster than was predicted when the new network structure for the Stockholm area was developed. Population growth, application for new point-loads, developed infrastructure and reduced production in the area are the main reasons for the increased need.

Svenska kraftnät is therefore forced to plan additional reinforcements in the form of a new north-south 400 kV connection, known as Storstockholm Väst, through the western part of the region. It is intended to replace the current 220 kV connections on the Hamra – Overbye – Beckomberga – Bredäng – Kolbotten stretch, and between Odensala and Overby.

Storstockholm Väst will also bring a need for control desk measures and new stations. The investment is roughly estimated to around four thousand million SEK.

**SydVästlänken (The SouthWest Link)**

The planning of SydVästlänken started after the major interruptions in 2003 which knocked out the electricity supply in southern Sweden and on Zealand. It was deemed necessary to strengthen the power grid in southern Sweden with another connection from the middle to southern Sweden.

Over the years, the focus has increasingly been shifted from reliability to a desire to overcome the internal bottlenecks in southern Sweden. The division into electricity regions in 2011 has illustrated the market impact that these limitations on the transmission ability can have. The project SydVästlänken will increase transmission capacity through interface 4 with around 25 percent.

SydVästlänken consists of two parts that meet in Barkeby station, just north of the Lake Nässjö. The northern part was taken into operation at the beginning of 2015 and is made up of a 180 km long 400 kV AC overhead line to Hallsberg. The southern part consists of two AC-connections of 600 MW each on the 250 km long section between Barkeby and Hurva. On this route 190 km has been built as land cable and 60 km as overhead line. The SydVästlänken is put into operation in two phases during 2016.

**Gotland**

Gotland is not connected to the national electricity grid, but is served by two cables that are part of Vattenfall’s regional network. Today the capacity limit has been reached on these cables. This prevents continued expansion of wind power on the island.
Considering the Government’s energy and climate policy ambitions, Svenska kraftnät has deemed that the State to have a responsibility for creating conditions for continued use of the favourable wind situation on the island of Gotland. In 2013 Svenska kraftnät therefore applied for concession to connect Gotland to the mainland by a new HVDC-connection to Misterhult, north of Oskarshamn. In the Perspective plan 2025 the new links were scheduled for 2015–2020.

During the autumn, Svenska kraftnät along with Vattenfall and Gotland’s Energy (GEAB) made a renewed study. The aim has been to ensure that Svenska kraftnät’s new connection be designed in a way that not only allows development of new wind power in the short term, but also be suitable from a system point-of-view in the long term, i.e. when Vattenfall’s two connections grow old and reach retirement.

The joint study is now completed, advising a different technical solution that is better suited to secure long-term supply of Gotland. Instead of a new DC-connection for 500 MW, Svenska kraftnät now plans building a 220 kV AC link for 300 MW. The AC power solution is made feasible by building with 220 kV instead of with 400 kV. It does not mean a radically lower cost than a DC cable with the same capacity, but provides a much more robust solution, that is not as dependent as the technically demanding power converters.

Capacity 300 MW is considered fully adequate according to the analyses that have been made. Combined with more efficient use of today’s links, connection of an additional 400 MW plus wind power on the island is made possible. Today 180 MW are connected.

The new solution means that Gotland is linked into the Nordic synchronous area and that a separate frequency regulation will no longer be needed. Greater freedom of action is also created by the end of 2030s, when Vattenfall’s DC-links are retired.

The new design will reduce land incursions on Gotland. On the mainland side construction of an inverter plant in Misterhult is avoided. Instead, the Gotland-link may be connected to Ekhyddan near the coast.

Svenska kraftnät will now promptly revise and supplement the company’s application for concession. If concession can be granted in the third quarter of 2017, taking into operation is deemed possible in 2021.

A second phase could be built if and when wind power development on Gotland requires additional transmission capacity to the mainland. No planning for a second phase, however, will be started during this plan period.

**West Sweden**

Although the earlier plans for extensive wind mill park development in Västergötland, Bohuslän and Dalsland counties have been reduced, a new north-south 400 kV line between Skogssätter and Stenkullen is very important.

There are currently only two north-south 400 kV transmission lines north of Gothenburg and during operation, transmission capacity has to be adapted to handle a situation where one line falls out. The load in the parallel 130-kV grid is so high that a fault in the National Grid is likely to redirect so much power into the underlying regional network that it will collapse. The new line Skogssätter - Stenkullen prevents this and at the same time removes current limitation in the west coast interface, which determines how much power that can be exported to NO1.

Management’s positive attitude has increased significantly since Vattenfall indicated its willingness to dismantle two nuclear blocks at Ringhals. It would reduce production capacity in Western SE3 with nearly 1,800 MW. Because the production loss must to a large extent be compensated with supply from the outside – for example from Swedish and Norwegian hydro power – the significance of a new north-south direction will increase over time.

A nuclear phase-out also reduces the capacity for voltage regulation on the west coast, which in turn reduces the chances for supplying power to the region in a reliable way. In order to compensate for the loss of Ringhals’ voltage regulation, Svenska kraftnät plans to replace the current automatic voltage control equipment in Stenkullen and install four new shunt capacitors.

Four 400 kV lines between Trollhättan and Varberg are now more than 60 years old and badly in need of renovation. Both poles and phase lines have been corroded by the salt-saturated wind. Work to replace these lines with a total length of 18 km must begin, but will not have time to be completed during the plan period. This is partly because of the long approval processes, and also by the limited possibility for turning off these heavily used lines.

**Power increases in nuclear power plants**

The Forsmark nuclear power plant has had alterations made to raise the thermal effect in the blocks F1 and F2. The power-enhancing measures in F2, and also the necessary permits, are ready and input from the block to the net has increased.

Increased input from F1 requires a new 400 kV line to be built between Forsmark and Stackbo to cope with the increased power flows and manage the transient stability in the region. Only when the new line has been put into operation, the F1 can be allowed to increase its input. The block will then also have a redundant supply to the National Grid, which reduces the number of incidents with change-over to the so-called house turbine operation and thereby increases reliable operation in the region. It is not clear whether Forsmarks kraftgrupp, which has to fund the line, will want to move on in order to make the increased input from F1 possible. While awaiting their decision, however, Forsmark - Stackbo remains a project.

Design of new lines for handling increased power input from F3 has been cancelled, since Vattenfall in November 2014 announced that no thermal power increase will take place in F3.
In the Oskarshamn nuclear power plant thermal power has been increased in O3. Measures have been taken to increase O2’s efficiency. To address this, the sectioned station at the nuclear power plant has been replaced by two new National Grid stations located next to each other. O1 and O2 are connected to one station and O3 for the other.

**A new north-south line on the East Coast**

A new 400 kV line, approx. 20 km long, will be built from Ekhyddan in SE3 via Nybro to Hemsjö in SE4. When the foreign link NordBalt is connected to Nybro, the power transport through the area will increase by 700 MW. The line is then needed to improve the grid’s transmission ability and to increase reliability by ensuring that the parallel regional network in Småland is not overloaded and disconnected by faults in NordBalt. Until the line can be put into operation, a system protection will be installed, which can disconnect the NordBalt by a critical fault.

The line’s connection in Ekhyddan also contributes to stabilise the generator in O3 in the Oskarshamn nuclear power plant, so that the block achieves the reliability that Svenska kraftnät requires of affiliated production facilities. This is especially important when E.ON now has announced that O1 and O2 will be closed. It namely causes O3 to have an even more important role for power stability in the area.

The line project has been deemed so important for the development of the single electricity market in Europe that the project has been awarded status as a Project of Common Interest (PCI) by the European Commission.

Affected municipalities, landowners and interest groups have protested against the new line and demanded that it should be buried. A land cable on such a long-distance stretch, however, requires for technical reasons a switch to DC power technology, which is not feasible in this case. Only AC technology allows the automatic reallocation of power flows by a design error, which is the purpose of the connection.

Even if it were possible to use DC power technology and thus lay the ground cable, such a solution would also be unreasonable for purely economic reasons. Compared with an overhead line a DC ground wire could save around 380 hectares of land to an estimated additional cost of slightly more than 11,000 million SEK. This means that the “saved” land would have to be valued at more than 30 million SEK per hectare.

**The grid around Lindbacka**

Plans for Svealand bring about reconstruction as well as new building of several National Grid stations. This includes, among other things, a new station Karlslund near Lindbacka. The Karlslund project also includes the construction of a new 220/130 kV transformer, a new 220 kV line to Lindbacka and tearing parts of Lindbacka old 220 kV station.

Shunt compensation is to be installed in Karlslund as one of several measures to increase the capacity in the short term over interface 2. Ultimately, the 220 kV station Finsslätten may be decommissioned if Vattenfall strengthens its network in the area. From Karlslund, near Lindbacka, the network is tied to the northern branch of SydVästlänken via a new line from Karlslund to Ostansjö.

The station Stackbo is being renovated in 2015. Smaller measures are also applied in the area. Such a measure is the sea lane on Mälaren, where the horizontal clearance for boats has been raised. This means that one power line has been rebuilt with 90 meter high poles at the passage of the Lake Mälaren.

Finally, renewal of four lines in SE3 is planned as well as a
## Ongoing Projects SE3

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### PLANNED PROJECTS, SE3

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7.3.4 Under consideration

If the voltage is increased to 400 kV between Västerås and Hallsberg, a number of 220 kV stations will have to be replaced with new 400 kV stations.

The network structure in the area to the south of Skara is being assessed. A new station that may come up is Larv, which then becomes the new entry point to the underlying 130 kV network. Larv will then replace Vattenfall’s transformer in Moholm.

Interface 2 will be reinforced by shunt compensation, i.e. installation of capacitors in Karlsund and other National Grid stations. It implies a capacity increase in interface 2 of around 500 MW.

In Horndal, there may be a need for a new 400/220 kV transformer to facilitate future wind power connections. The construction of such a station is coordinated in time with the planned renewal of the 220 kV station in Horndal. The transformer also involves an increased short-circuit power and reduced problems with power quality for industry connected to Horndal.

The 400 kV line previously planned from Ängsberg via Horndal to a new National Grid station in Dingtuna (Västerås) and then on to Karlslund, was heavily dependent on the plans for Forsmark and Stockholm’s Electricity. Further power increases in Forsmark are now cancelled and Metropolitan Stockholm West has been added to complement the Stockholm Electricity. Overall there is no longer a reason to build the line.

However, the need to renew station Himmeta remains, which is at present built for 220 kV. The line between Himmeta and Karlslund is run at this voltage level but is built to 400 kV standards. When Himmeta is to be renewed, Svenska kraftnät will therefore consider an upgrade to 400 kV.

SVC\textsuperscript{37}-facilities in Hagby and Stenkullen have exceeded their technical service life. They are in such poor condition that parts of the plants have already been shut down. Spare parts for the plant sections that still work, are in short supply, so that SVC facilities need to be replaced.

Fenno-Skan 1 is the oldest HVDC-connection to Finland and was built in 1989. Long term it needs to be replaced. At that time it cannot be excluded that a different route than the current one could provide more advantages to the electricity market. Whether the line is to be renewed in the existing route or replaced by a new link at another site will be examined.

Parts of the older 220-kV network in eastern Svealand need to be upgraded over time in order to secure future reliability. There are not yet any concrete plans, so the actions required will be investigated.

As mentioned in section 7.3.3 a complete reinvestment in four 400 kV transmission lines on the west coast is considered. These are Horred – Breared, Skogssäter – Kilanda, Kilanda – Stenkullen and Stenkullen – Horred. The redevelopment is complex and time-consuming, because several of the lines are co-located with other wires. They also depend on each other in terms of capacity allocation. For one, Stenkullen – Horred, technical feasibility study is underway.

Many of the stations in the region reach their technical lifespan during the ten-year period. Renewal of nearly 20 stations will therefore need to begin.

Finally, some 15 top-lines to be exchanged with new opto connections as well as several status-raising line measures are under consideration.

\textsuperscript{37} SVC = Static Var Compensator – equipment for voltage control.
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<td>2022</td>
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<tr>
<td>612</td>
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<td>1/2018</td>
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<td>Tenhult FT188 station renewal</td>
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<td>Kolstad-Barkeryd-Tenhult FL9 S3-4 opto</td>
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<td>2024</td>
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<td>2025</td>
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<td>1/2017</td>
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<td>Måby-Hagby KL41 S4-6 line renewal</td>
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<td>2/2017</td>
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Forts. nästa sida
### Projects Under Consideration, SE3

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<th>Feasibility Study</th>
<th>Decision</th>
<th>Operation</th>
<th>Cost (m SEK)</th>
<th>Motive</th>
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<td>2025</td>
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<td>687</td>
<td>Plenninge-Ödensala KL42 S2-3 line renewal</td>
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<td>1/2018</td>
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<td>732</td>
<td>Hall FT81 station renewal</td>
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<td>Malsta RT192 station renewal</td>
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<td>2027</td>
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<td>640</td>
<td>Horred-Breared FL14 S3-4 line renewal</td>
<td>1/2016</td>
<td>1/2017</td>
<td>2028</td>
<td>1 000</td>
<td>Reinvestment</td>
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<tr>
<td>608, 616</td>
<td>Hallsberg-Timmersdala- Stenkullen FL5 S1-4 opto</td>
<td>2019</td>
<td>2020</td>
<td>2028</td>
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<td>658</td>
<td>Edinge-Gråska RL11 S3-4 opto</td>
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<td>2028</td>
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<tr>
<td>659</td>
<td>Kolbotten-Hall-Hedenlunda FL8 S1-4 opto</td>
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<td>2028</td>
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<td>664</td>
<td>Odensala-Kolbotten FL4 S1-4 opto</td>
<td>2025</td>
<td>2025</td>
<td>2028</td>
<td>15</td>
<td>Reinvestment</td>
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<td>673</td>
<td>Horndal-Untra KL11 status measures &amp; opto</td>
<td>2020</td>
<td>2021</td>
<td>2028</td>
<td>220</td>
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<tr>
<td>728</td>
<td>Finnslätten RT25 station renewal</td>
<td>2024</td>
<td>2025</td>
<td>2028</td>
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<tr>
<td>700</td>
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<td>2022</td>
<td>2023</td>
<td>2030</td>
<td>30</td>
<td>Reinvestment</td>
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</tbody>
</table>
7.4 Malmö region (SE4)

7.4.1 About SE4

Region SE4 includes Skåne and Blekinge counties, and parts of Kalmar, Kronoberg and Halland counties. A large proportion of the consumption takes place in the Malmö/ Lund region and in the towns along the coast – Trelleborg, Ystad, Helsingborg, Karlskrona and Kalmar.

Towards the north interface 4 consists of five 400 kV transmission lines. The interface follows a line from south of Oskarshamn on the eastern coast to the south of Varberg on the west coast. In addition, eight 130 kV regional network lines run across the interface in parallel to the National Grid.

Four connections abroad run from SE4. They are two 400 kV AC power cables to Zealand (DK2), the DC Baltic Cable connection to Germany and the DC connection SwePol Link to Poland. At the beginning of 2016, the new DC connection NordBalt to Lithuania goes into operation. In addition, there are links at regional network level by means of four 130 kV AC power cables to DK2. Altogether, these connections have an export capacity of 3,200 MW and an import capacity of 3,600 MW.

As shown in Table 17, the installed power from the production plants in SE4 is about 4,700 MW. 1,600 MW of this, however, is back-up power, such as condensing power plants and gas turbines, so only about 3,100 MW are at electricity market disposal. It should be compared with the area’s maximum power consumption of approximately 5,000 MW.

SE4 is the largest deficit area in Sweden and the region in the country with the lowest production capacity. In 2014 the electricity deficit in SE4 was about 16 TWh.

Exports to continental Europe and Baltic countries are expected to increase by 2025. This is, among other things, a result of NordBalt and is made possible by the new link Syd-Västlänken across interface 4.

Investment needs in SE4 are clearly linked to the area’s role as a starting point for many transmission links to the outside areas. Today, Svenska kraftnät only has enquiries for connecting 500 MW of new wind power in SE4. In the long term, however, connection of offshore wind power parks may become relevant.

Lines in southern Sweden, and notably on the west coast are getting old. West coast climate with its salty winds wears on National Grid area facilities. SE4 has several wires that are older than 60 years and where large upgrade needs exist.

During the ten-year period, renewal of three lines is planned on a line stretch of about 150 kilometres. Furthermore, replacement of the top lines is planned on several lines. Over the 10-year period Svenska kraftnät sees a need to begin the renewal of about 220 kilometres of SE4’s 400 kV network.

Planned reinvestments in the station facilities are, above all, about renewal of five stations. In addition to those, a large number of changes are also planned in various components in primary equipment and control facilities.

<table>
<thead>
<tr>
<th>POWER TYPE</th>
<th>PRODUCTION 2014 (TWh)</th>
<th>PRODUCTION 2025 (TWh)</th>
<th>INSTALLED POWER 2014 (MW)</th>
<th>INSTALLED POWER 2025 (MW)</th>
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<td>Hydro power</td>
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<td>1</td>
<td>350</td>
<td>300</td>
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<tr>
<td>Nuclear power</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wind power</td>
<td>3.5</td>
<td>5</td>
<td>1,500</td>
<td>2,200</td>
</tr>
<tr>
<td>Combined heat and power</td>
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<td>4</td>
<td>1,250</td>
<td>1,200</td>
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<td>Solar power</td>
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<td>N/E</td>
<td>300</td>
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<td>Condensate power and gas turbines</td>
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<td>0</td>
<td>1,600</td>
<td>1,600</td>
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<td>TOTAL PRODUCTION</td>
<td>8</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption</td>
<td>-24</td>
<td>-25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BALANCE</td>
<td>-16</td>
<td>-15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8. The figures for installed power in 2014 are rounded off and taken from Elåret 2014, Svensk Energi. They have been allocated over regions based on the Svensk Kraftnät’s measurements. The values for 2025 are Svensk Kraftnät’s estimates.
7.4.2 Project overview SE4

Figure 22. SE4 - All projects.
7.4.3 Ongoing and planned

There are four current major reinvestment projects in SE4. The stations Barsebäck and Söderåsen are being renewed and also, the line Hurva – Sege and AC connections to Zealand (DK2).

Two stations are built in Nybro and Hurva. The stations are part of the projects NordBalt and SydVästlänken, respectively, and include both AC switching equipment and inverter stations for the DC power connections.

The DC connection NordBalt between Sweden and Lithuania is put into operation at the beginning of 2016 and ties the emerging Baltic electricity market more strongly to the Nordic. Grid reinforcements are required in eastern Götaland for the regional grid in Nybro area to maintain operational reliability after the connection of NordBalt. Initially this is solved by installing system protection that disconnects NordBalt if a critical fault occurs. In the early 2020s this is replaced with the new line from Ekhydian in SE3 through Nybro to Hemsjö described in section 7.3.3. The system protection will then be retained only for increased reliability.

In early November 2015 Svenska Kraftnät signed a cooperation agreement with the German system operator 50 Hertz with focus on building a DC cable between the Skåne south coast and the German coast, west of Rügen. The connection will be built with VSC38-technology. Proposed access points to the AC network are Hurva and Güstrow, respectively.

The project is called Hansa PowerBridge and has its main motivation in providing the market with access to increased capacity to take advantage of the fluctuations in production and consequently electricity price that occurs with an ever larger share of weather-dependent electricity generation. Increased capacity between Sweden and Germany is also likely to improve the supply reliability through better opportunities for imports from Germany.

Socio-economic benefit analysis for Hansa PowerBridge has been made in the perspective planning work as well as before the conclusion of the cooperation agreement with 50 Hertz. Based on these analyses, the parties have agreed to build the connection with a power capacity of 700 MW.

The benefits of a duplicate link (2 x 700 MW) have even been analysed but indicated no positive European or Swedish net present value in any of the scenarios analysed. The parties may, however, expand the link at a later stage changes if assumptions change.

Today northern Germany is a surplus area and the ability to transmit electricity to the south of Germany is limited. Very large network investments are, however, planned in the German network, among other things, several DC corridors from north to south. These reinforcements are a prerequisite for making the building of Hansa PowerBridge interesting for Sweden. Hansa PowerBridge is projected to be operational by 2025.

Some respondents have called for an additional international connection to Poland. This is not, however, deemed relevant during the plan period. One reason is that the internal constraints of the Polish network are much too extensive, which today finds expression in a too low utilization of the connection that we already have, SwePol Link.

No station renewals or major line actions have at this time reached technical feasibility planning. The two feasibility stu-

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**ON-GOING PROJECTS, SE4**

<table>
<thead>
<tr>
<th>NO</th>
<th>PROJECT</th>
<th>PHASE</th>
<th>OPERATION</th>
<th>COST [M SEK]</th>
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<td>782</td>
<td>NordBalt HVDC-station</td>
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<td>2016</td>
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<td>NordBalt Ground cable</td>
<td>Construction</td>
<td>2016</td>
<td>185</td>
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<td>785</td>
<td>NordBalt submarine cable</td>
<td>Construction</td>
<td>2016</td>
<td>1,480</td>
<td>Market integration</td>
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<td>191</td>
<td>SydVästlänken Hurva DC</td>
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<td>2016</td>
<td>1,225</td>
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<td>425</td>
<td>Hurva-Sege FL24 53-4 line renewal</td>
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<td>Market integration</td>
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<tr>
<td>793</td>
<td>Nybro-Hemsjö new 400 kV-line</td>
<td>Decided</td>
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<tr>
<td>772,973</td>
<td>Söderåsen FT12 station renewal incl. reactor X1</td>
<td>Procurement</td>
<td>2017</td>
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<td>341</td>
<td>Zealand-Sweden 400 kV cable exchange</td>
<td>Decided</td>
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<td>300</td>
<td>Barsebäck FT76 station renewal</td>
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**PLANNED PROJECT, SE4**

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<th>OPERATION</th>
<th>COST [M SEK]</th>
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38. Voltage Source Converter
dies in progress relate to the upgrading of opto links and a line relocation in Staffanstorp.

### 7.4.4 Under consideration

Two new locations for wind farms need to be built in SE4 before 2025.

A renewal of the station Alvesta will start in the next few years. Two additional station renewals – Arrie and Karls- hamn – begin a few years into the 2020s.

Two major line renewals are Breared – Söderåsen and Sege – Barseback. Additionally renewal of the opto links on four line sections is needed. Technical feasibility studies will begin in the next few years.

#### PROJECTS UNDER CONSIDERATION, SE4

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<tr>
<th>NO</th>
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<th>FEASIBILITY STUDY</th>
<th>DECISION</th>
<th>OPERATION</th>
<th>COST (M SEK)</th>
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<td>On-going</td>
<td>2020-2028</td>
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<td>Connection of production &amp; network</td>
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<td>2023</td>
<td>2026</td>
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<td>Sege-Barsebäck FL7 S7-8 line renewals</td>
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<td>2028</td>
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<td>1/2018</td>
<td>2029</td>
<td>1 150</td>
<td>Reinvestment</td>
</tr>
</tbody>
</table>

#### Offshore wind

Any offshore wind is a major uncertainty in the planning of the grid design in SE4. Blekinge Offshore, Kriegers Flak and the Södra Midsjö bank are examples of three major parks where a connection to SE4 could become relevant in the future.

Uncertainty, however, has so far been too big to make sense from deeper studies of such connections.

#### OTHER RENEWALS

In addition to the renewals as reported above per region, there are several long-term reinvestment programs related to equipment located throughout the country. This is mainly a large number of individual devices and control facilities.

These investments are individually not significant for overall cost but the total volume is. In total there are some 40 to 50 devices in a varying number of stations to be replaced every year, so that closer to 500 appliances will be changed during the plan period. In addition, reinvestment in five transformers is planned plus 15 reactors and 10-15 control facilities.
8. THE INVESTMENT VOLUME

The network investments estimated in Network Development Plan 2016-2025 are a major financial commitment. The projects listed in the plan add up to a total investment volume of around 55,000 million SEK.

Over the planning period they are in the range of 45,000 million SEK. Of these, investments in new lines and stations constitute about 25,000 million SEK. Reinvestment requirements during the plan period are estimated at nearly 20,000 million SEK.

Investments in the Swedish National Grid have in recent years reached a level, which in a historical perspective is very high. A very rough breakdown of investments among the three driving forces – connection of electricity generation (wind power), reinvestment and market integration – are shown in Figure 23. The graph shows gross figures, i.e. various kinds of investment grants are not included.

The indicated volumes of investment are of course subject to some uncertainty. Investments that are in their implementation phase are more likely to come out closer to the specified plan than investments in the planning phase, which are less certain. Please note in particular that planned wind power connections frequently are cancelled as a result of, for example, financial difficulties or reduced cost-benefit assessment by the wind power developer.

Even more uncertain are investments currently only categorised as under consideration. There is a risk that they are either cancelled or that amounts and schedules change. Figure 24 shows how much of the annual investment volume that come from investments in each phase and therefore give some indication of expected annual accuracy in network Development Plan 2016-2025.

Based on the logic above, one might assume that the annual investment volume will end up slightly lower than currently specified in the plan. On the other hand, however, potential increased expenses as well as additional, currently unexpected network development can become necessary or urgent. Overall, the company therefore makes the assessment that the indicated investment volume currently represents a reasonable estimate at an aggregated level.
8.1 Financing of investments

Svenska kraftnät’s investments are financed mainly by borrowing and by internally generated funds. The company has two additional, important sources for funding.

The first is the investment contributions. New power generation requires the network companies to connect the production. If there is no spare capacity in the network, the connecting producer has to pay an investment contribution to cover those network investments specifically required to connect the production plant. In addition, investment contributions from property owners may occur, for example when network expansion leads to release of valuable land. A third type of investment contribution is EU funds granted for investments considered to have a European value. An example of this is the project NordBalt, which received contributions from EU funds.

The second is capacity charges (the so-called bottleneck revenue). Capacity charges are generated when there are price differences between adjacent areas (countries or Swedish electricity regions).

According to the EU Regulation (EC) no 714/2009 capacity charges between countries must be used either for counter trade to ensure that the allocated capacity on the connections is available to the market or for network investments that increase the capacity and in the long run remove the bottlenecks which cause the price difference. In addition it gives an opportunity to generate funds, and on an exceptional basis – with the approval of the Energy Market Inspectorate – to lower network rates. In accordance with the company’s regulatory letter the Svenska kraftnät applies the EU regulation also on the fees generated by the capacity bottlenecks between the Swedish electricity regions. Capacity charges are, however, very incalculable and volatile.

Figure 25 indicates the assessed distribution between the different sources of financing for investments by 2025.
8.2 Svenska kraftnät’s financial evolution

Investments in Network Development Plan 2016-2025 will have significant consequences for the company’s finances and for the National Grid tariff to be charged to network customers.

The financial position is also highly dependent on a number of factors arising from investment and which in many cases are difficult to forecast accurately. The additional level of investment will have a direct impact on the company’s costs by increased depreciation and interest payments but also indirectly through increased costs for operation and maintenance of a growing family of installations.

8.2.1 The conditions for the financial evolution

An estimate of what Network Development Plan 2016-2025 involves for the company’s financial position and for network customers’ cost development to 2025, requires a range of assumptions.

Svenska kraftnät currently has a required rate of return from the Government of six percent of adjusted equity over a trade cycle. This is assumed to apply unchanged during the period. However, the Government has announced a review of the yield requirement. If the review leads to an increase in the required rate of return, this will have significant effect during the ten-year period.

The main increase in estimated cost caused by the company’s investments, consists of interest expenses and depreciation. The current interest rates in Sweden, with interest rates near and even below zero, are unusual. The development of Svenska kraftnät’s loan rate from the Swedish National Debt Office follows the repo rate and the long-term development is hard to forecast.

In order to forecast interest rates the company uses Konjunkturinstitutet’s forecast as a basis, and the same holds for inflation assumptions. On the basis of the company’s planned, high loan financing, any deviation from the assumed interest rate levels will be of great importance for the company’s financial position and for the future tariff levels. Forecasted levels are shown in Figure 26.

Both capacity charges and cost of counter trade are very difficult to estimate. The price of electricity and the price differences that arise between the regions are dependent on a number of factors such as temperature, availability of water in dams, nuclear energy’s availability and the interconnection capacity between the regions and abroad. These factors are difficult to assess even one year ahead. How the situation will be in ten years is even harder to assess.

The revenue from capacity charges is estimated at an annual amount of between 700 and 800 million for the period 2016-2025. Under these conditions, the annual counter trade costs (currently about 20 million SEK) are more than compensated by capacity charges during the period until 2025, even though they could rise. The vast majority of the capacity charges may thus be used to finance investments.

8.2.2 Svenska kraftnät’s financial position

The high investment rate will significantly affect Svenska kraftnät’s balance-sheet. Under these conditions and unchanged financing principles, rate of return and dividends to the Government (65% of profit), the company’s loan financing in 2025 will be in the order of 25,000 million SEK. This assumption is of course subject to great uncertainty.

That equates to a debt/equity ratio of 270 percent, compared to the current maximum debt-equity ratio of 140 percent. The equity ratio by 2025 is estimated at about 18 percent. The development is, however, strongly dependent on the assumed input values. Forecasted evolution is reported in Figure 27.

39. The amount does not include any increased loans for onward lending to regional and local network owners within the framework of what is called network reinforcement loans. As long as the newly established procedure is in force, the amount may thus be increased by up to about 700 million SEK, and then gradually decreasing as the loans are repaid. The amount does also not include any cash (in the area of 700 million SEK) that Svenska kraftnät may need to provide as collateral when purchasing transmission losses. Today the company is able to use bank guarantees as collateral but this possibility can be discontinued after March 2016.
The financial key figures shown above are notable and would, if Svenska kraftnät were not a part of the State, present the image of a strained financial situation. As a public authority, however, these key figures become less relevant. The company can borrow from the Swedish National Debt Office, regardless of the level of financial ratios, as long as the Parliament has approved the loan framework.

8.2.3 National Grid tariff

The costs generated by Svenska kraftnät’s network investments are ultimately paid by the end-customers. Svenska kraftnät charges for all input to and consumption from the National Grid through the National Grid tariff, and the power charge shall primarily cover the increased costs that investments generate.

Under these assumptions and in view of the projects presented in Network Development Plan 2016-2025, costs of operation, management and development of the National Grid are projected to increase by a total of about 100 percent during the period. It is important to note that the estimate applies in general to the entire network community. For the individual network customer the result may come out differently, depending on the fee structure and where in the network the customer is connected.

Figure 28 illustrates the development of Svenska kraftnät’s total tariff revenues (power charges), under various assumptions about the repo rate path. The effect of a higher interest rate, which is given below, looks modest at first sight in view of the high loan financing. What is not shown in the figure, however, is that a higher rate also affects

40. The second part of the National Grid tariff (in addition to the power fee) is the energy charge. Energy charge shall cover the company’s costs for covering the transmission losses caused in the National Grid. The evolution of the energy charge is therefore largely dependent on electricity prices and only indirectly by the network development through the increases or decreases in the losses that this gives rise to.

41. This means that the interest rate for these investments are not charged to the profit and loss account during the current year, but will be included in the investment and is charged as an expense, through depreciation, only when the plant is put into operation.
the investment cost since the company capitalises interest (interest during construction period) of the largest investments\textsuperscript{41}. This means that a higher interest rate makes the investment become more expensive and therefore the cost of depreciation is higher across the total depreciation period, i.e. largely beyond 2025.

8.3 Svenska kraftnät’s mission and financial challenges

Svenska kraftnät determines the level of the National Grid tariff on the basis of the Government’s required rate of return on the company. Like any other network company, however, Svenska kraftnät’s revenue is governed by the revenue framework established by the Energy Market Inspectorate. Currently – and with the required rate of return imposed on Svenska kraftnät and the WACC\textsuperscript{42} adapted by the Inspectorate – the revenue framework provides sufficient room for the company’s revenue needs. The network development involves some challenges, however, that could significantly complicate the company’s ability to stay within the framework.

Firstly, the revenue framework applies a depreciation time for cables and stations of about 40 years. That exceeds Svenska kraftnät’s depreciation time of 30 years or less and in some cases even the technical life span. The consequence of this is that certain installations may not be in operation for sufficient time to allow the company to have full cost recovery for them.

Secondly, the regulatory requirement of return (WACC) is applied only on plants that are taken into use, while Svenska kraftnät of course also has capital costs for ongoing investments. The latter may well be considered to be part of a future change in return requirements from the owner, which in this case means that a lower rate of return requirement on the company than the regulatory WACC nevertheless can make the revenue need greater than the revenue framework.

Finally, the revenue framework also includes requirements to improve the efficiency on what the regulation names controllable costs. These include, among other things, personnel costs, operation and maintenance. The expansion of the National Grid will lead to higher levels for all these cost items, even if the company increases the cost-effectiveness per plant. This is not taken into account in the regulation. In the longer term, it can become difficult to stay within the levels which the regulation allow.

Another challenge for the projected tariff increase is European legislation. According to Commission Regulation (EU) 838/2010, the value of the annual average transfer fees paid by producers in Sweden shall not exceed 1.2 euro/MWh. For Svenska kraftnät the annual average transfer fees paid by producers in 2014 was 0.73 €/MWh.

Based on the forecasted rate increase, there is thus a risk that this limit will be exceeded, unless the split between consumers and producers is changed to the detriment of consumers. Such redistribution seems illogical, because a significant part of the investment is justified by benefit for the producers. For a cost-justified National Grid tariff where the right operators’ group covers the costs they generate, it is to be maintained, it is reasonable that the producers carry their share of the company’s increased costs.

The requirements for financial resources to implement this plan are comprehensive. Network Development Plan 2016-2025 reflects, however, the Government’s mandate to Svenska kraftnät and the regulations that govern our activities. Svenska kraftnät has an obligation to provide connection, according to the Electricity Act and much of the company’s facilities will soon achieve their technical life and need to be renewed. A significant proportion of the investment plan is therefore inherently compulsory. In addition, according to the company’s instructions\textsuperscript{43}, Svenska kraftnät shall develop the core network based on socio-economic cost-benefit assessments. Such assessments should not only be national. The Nordic Council of Ministers has asked the Nordic grid operators to develop the network from a Nordic benefit perspective. In order to allow harmonisation of electricity prices, ensure energy reliability, promote efficient use of resources and reduce carbon emissions, it is important that the investments motivated by market integration are implemented.

\textsuperscript{41} Weighted average cost of capital specifies the return on total capital requirement.

\textsuperscript{42} Decree (2007:1119) with instructions for the business Svenska Kraftnät.
Our society is dependent on electricity. Svenska kraftnät is responsible for ensuring that Sweden has a safe, environmentally sound and cost-effective transmission system for electricity - today and in the future. We achieve this in the short term by monitoring the electrical system around the clock, and in the long term by building new power lines to meet tomorrow’s electricity needs.