Assessing Finland's Energy Security in Different Energy Policy Scenarios

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ABSTRACT

Finland updated its energy and climate strategy in late 2016 with the aim of increasing the share of renewable energy sources, increasing energy self-sufficiency and reducing greenhouse gas emissions. Concurrently, the issue of power capacity adequacy has been present in the political discourse in Finland, especially since the record-high demand peak in January 7th 2016. This paper analyses the Finnish energy system in years 2020 and 2030 by using the EnergyPLAN simulation tool to model, whether different energy policy scenarios result in a lack of power capacity. Moreover, the implications of a severe drought on the Finnish energy system are modelled and analysed. The results show that the scenarios of the strategy result in a better adequacy of power capacity and that the implications of an extreme drought in Finland on capacity adequacy are relatively low comparing to the reduction in annual electricity production with hydropower.

KEYWORDS

Energy security, energy policy, power capacity adequacy, climate change, energy system modelling, energy markets, hydrology, drought

INTRODUCTION

Finland updated its national Energy and Climate Strategy (the Strategy) in November 2016, which presents a roadmap to achieve the national targets on inter alia increasing the share of renewable energy sources (RES) and reducing greenhouse gas (GHG) emissions by 2030. Concurrently, the issue of power capacity adequacy during winter demand peaks has grown more topical, especially after the record high demand peak in Finland in early 2016. Despite the record-high demand, no shortages in the power supply were experienced and, moreover, the Transmission System Operator (TSO) of Finland, Fingrid, did not have to resort to any capacity reserves during the peak. However, trends in the electricity markets during the past decade, such as increasing wind power capacity, prolonged low level of electricity spot price and decreasing thermal capacity, and the strategic objectives of further increasing the share of RES and phasing out coal in energy use both amplify the stresses related to security of supply.

Energy security related academic research often revolves around conceptualising energy security and composing indicators with which to compare states of nations with each other, i.a. [1]–[4]. Moreover, a large body of research analyses energy security related trade-offs, e.g. the relation between increasing the share of variable RES and system stability on EU level, i.a. [5], [6]. The Finnish energy system in 2030 has also been a subject of research, e.g. [7], but no academic research has yet been published in order to map the implications of national energy and climate targets on energy security. Energy security is a multidimensional issue, but due to the topicality of the subject, this study will concentrate on power capacity adequacy. The authors analysed power capacity adequacy during the record-high peak in winter 2016 in Finland [8] and found out that, despite the alarming trends, the Finnish power system would still have had technical capacity and adequate measures of intervention to cope with severe stress factors during the peak in 2016. However, trends in the Finnish energy sector cause reasons to anticipate the issue in the coming decades.

This paper analyses Finland's energy security in years 2020 and 2030 in the energy policy scenarios presented in the Strategy by modelling the implications of equivalent conditions as were experienced in early 2016 with the EnergyPLAN simulation tool on an hourly level. Furthermore, the authors also analyse a scenario with pessimistic assumptions as regards energy investments in Finland. Moreover, this paper analyses the interdependence between hydrological situation and energy markets by applying the effects of a severe drought in the Finnish power system in different policy scenarios and years.

Firstly, we review the structure of the Finnish energy system, mainly by presenting the composition of power and heating markets. Secondly, we introduce the contents and targets of the Strategy in more detail. Thirdly, we introduce the used simulation tool, EnergyPLAN, and input data for the modelling. Finally, we present and analyse the simulation results.

THE FINNISH ENERGY SYSTEM

The Finnish energy system has a few noteworthy characteristics: firstly, due to its geographical location and high share of energy-intensive industry, Finland's consumption per capita is high in both heat and electricity; Finland has the 7th highest electricity consumption per capita in the world [9]. Moreover, electricity and heating markets are strongly coupled via combined heat and power (CHP) production, which covers approximately 32 % of Finnish electricity production and 28 % of space heating. Secondly, Finland is a part of the Nordic electricity market and hence strongly connected with its neighbouring countries' power markets. However, Finland is also heavily dependent on cross-border energy trade: in addition to the large share of net electricity imports, Finland imports practically all of its fossil fuels and uranium. Moreover, a majority of the fuels are imported from Russia. The next chapters review the primary and final energy consumption and structures of electricity and heating markets in Finland, respectively.

Primary and Final Energy Consumption

Energy consumption can be measured either as primary or final energy consumption. Primary energy refers to the energy content in all fuels used, such as coal, gas, oil and uranium, whereas e.g. hydropower and wind power production are included *per se*. No conversion or distribution losses are considered when calculating primary energy consumption. Final energy consumption, on the other hand, refers to the useful energy available to the final user, including all conversion and distribution losses. National targets concerning e.g. the share of RES and energy self-sufficiency are calculated using the final energy consumption. The main difference between these two in Finland comes from the low thermal efficiency of nuclear power production.

Finland has a large share of energy intensive industry, which accounted for 45 % of the final energy consumption in 2016. Other significant sectors of energy consumption were space heating (26 %) and transport (17 %). The most important primary energy sources in 2015 were biomass (25.4 %), oil (23.7 %) and uranium (18.7 %). Final energy consumption by sector and primary energy consumption by energy source are presented in Figure 1. [10]

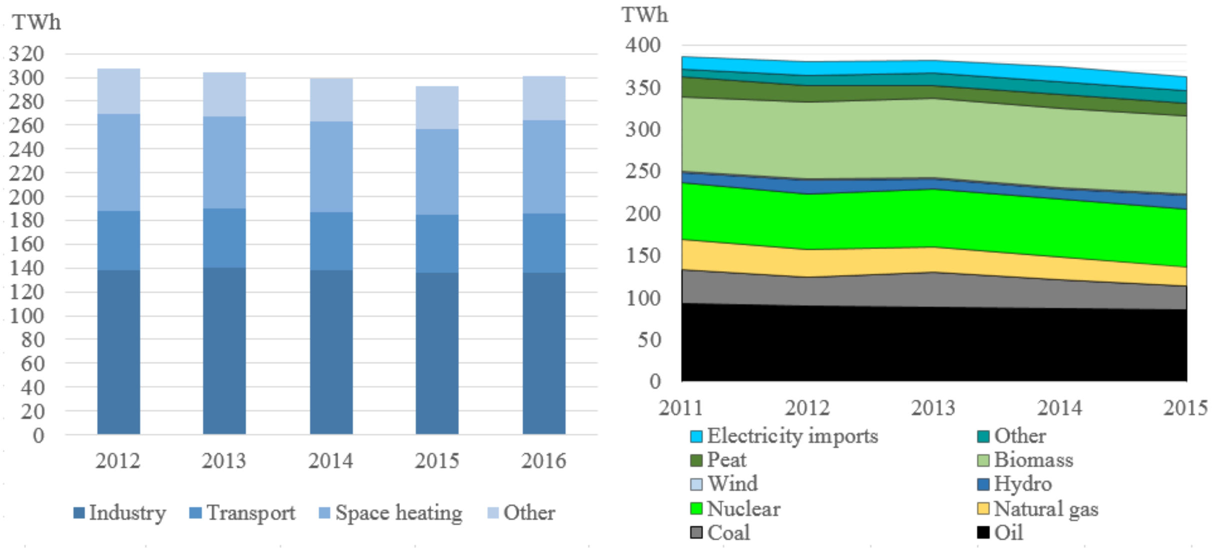

Figure 1. Final energy consumption in Finland by sector and primary energy consumption in Finland by energy sources

Electricity Markets

The Finnish electricity system is a part of the Nordic wholesale electricity market, Nord Pool, and hence strongly connected with its neighbouring countries' power markets. The prices for Nordic electricity markets are set in Elspot (day-ahead) and Elbas (intraday) markets. However, Finland is also heavily dependent on cross-border electricity trade: net electricity imports covered 22.3 % of the total electricity consumption in Finland in 2016 [11], of which most was imported from Sweden. Therefore, the Finnish power system cannot be analysed as an isolated entity. The main connections are with Sweden, Estonia and Russia, of which the two former are included in the common electricity market, whereas the connection between Finland and Russia is not a part of the trading system. In total, the cross-border transmission capacity allows Finland to import approximately 5,100 MW of power from its neighbouring countries, which is more than one third of the record-high hourly demand peak.

The Finnish electricity generation mix is highly diversified, comprising high shares of hydro, nuclear and thermal power production and an increasing share of wind power production. Industry and construction covered 47 % of the electricity consumption in 2016, residential and agriculture 27 %, services and public sector 23 % and transmission and distribution losses accounted for 3 % [10]. Total installed power capacity in Finland amounted to approximately 16,100 MW in the beginning of 2016 [12]. However, as some of the capacity is mothballed, some allocated as system reserves and the momentary availability of different technologies varies according to many factors, a more relevant figure is the estimated available capacity during the demand peak. Electricity supply by sources [9], total installed power capacity and Fingrid's estimation of the available power capacity during the demand peak in 2016 [10] are presented in Table 1.

Table 1. Finnish electricity production, installed power capacity and estimated available capacity during the winter peak in 2016

Production type	Consumption (TWh/a)	Installed capacity (MW)	Estimated available capacity during winter peak (MW)
Hydropower	15.6	3,180	2,550
Nuclear power	22.3	2,780	2,780
Condensing power plants	4.4	2,160	960
Combined heat and power, total	20.8	6,985	5,250
CHP district heating	*11.8*	*4,170*	*3,250*
CHP industry	*9.0*	*2,815*	*2,000*
Wind power	3.1	1,005	60
Net Import	19.0	-	-
Total	85.1	16,110	11,600

Electricity demand in Finland has not grown during the 2010s, but stayed around 82-85 TWh/a. The low demand has partly been caused by the economic downturn in Finland and partly by the exceptionally warm weather in the past years. The low demand has significantly reduced operating hours of especially condensing power plants, causing the plants to lose their economic feasibility. Hence, the commercially active condensing power capacity in Finland has reduced by more than 2000 MW since 2010. The last commercially operative condensing coal plant will partly be allocated in the peak load reserves starting from July 2017 and others have been mothballed or decommissioned earlier. Condensing coal power has traditionally been the price setter in the Nordic day-ahead market and it has been used for peak production. Simultaneously with the decreasing capacity of conventional plants, wind power capacity in Finland and in the Nordics has been growing rapidly – mainly due to national subsidy mechanisms. Wind power capacity in Finland was approximately 1005 MW in early 2016 and it is expected to double by the end of 2017 under the current feed-in tariff mechanism [13]. Moreover, wind power capacity in Sweden is experiencing similar trends with greater magnitude, which affects the Finnish power market via price level and availability of electricity imports.

Heating Markets

Due to its geographical location, Finland has a high demand for heat, especially during the winter. A major share of the heating demand is supplied with CHP production, which enables very high thermal efficiencies (> 90 %) in energy production. However, as efficient district heating utilisation requires dense enough demand for heat, housing in remote areas typically uses a combination of electrical heating, small-scale wood combustion and heat pumps.

Comparing with electricity markets, heating markets in Finland are much more scattered: Finland comprises a plethora of separate heating markets of different sizes, ranging from a district heating network of a large city to a single remote residential building. Hence, heating markets in Finland cannot be assessed as a similar entity as electricity markets and e.g. heating capacity adequacy should be assessed in each of the markets separately. Moreover, comparing with the electricity system, heating markets are not as sensitive as regards system balance and magnitude of implications of a fault in the system: heat accumulators are widely used to enhance balance in district heating systems and, moreover, an abrupt fault in a district heating network is less tangible to the end-user than one in a power system. However, the overall heating capacity connected to district heating networks amounted to 22,790 MW [14] in the end of 2015 and historically the adequacy of capacity in heating networks has not been an issue. Despite approximately two thirds of the heating capacity being heat only boilers, 69.7 % of district heating production was based on cogeneration in 2016.

NATIONAL ENERGY AND CLIMATE STRATEGY

The Finnish Government published a new National Energy and Climate Strategy [15] in November 24th 2016, which presents a roadmap to achieve the national targets on inter alia increasing the share of RES and reducing GHG emissions by 2030. The goal is to systematically set a course for achieving an 80-95 % reduction in GHG emissions by 2050.

The main targets of the Strategy by 2030 are following:

- 50 % share of RES in final consumption of energy
- 55 % self-sufficiency in energy production
- Halving the use of imported oil for energy comparing to the level of 2005
- Phasing out coal in energy production (with minor exceptions)
- 40 % share of RES in transport sector
- 39 % reduction in GHG emissions in the effort-sharing sector comparing to the level of 2005 (set by the Commission)
- 250,000 electric and 50,000 gas-powered vehicles

A key tool in the strategy work was calculating possible energy market development via assessing different scenarios. Rather than predictions, the scenarios are built on certain assumptions projecting different possible future outcomes. The main scenarios are Basic scenario and Policy Scenario, which are presented in the following chapters. In addition to the scenarios in the Strategy, an Alternative scenario with a set of pessimistic assumptions as regards e.g. power capacity investments Finland and new transmission lines to neighbouring countries is analysed. Alternative scenario is presented in chapter Methods and Data.

Basic scenario

Basic scenario assumes that no additional energy policy actions are implemented since those made before spring 2016. The scenario sets the baseline with which the possible required policy actions are compared and the impacts of any new measures on the energy and climate targets can be determined.

The share of RES will increase in Basic scenario, mainly due to an increase in the use of forest chips and waste liquors from forestry. Moreover, the use of heat pumps is estimated to increase with the current trends, while the strong increase in wind power production between 2010 and 2017 will slow down significantly without any new policy measures. Final energy consumption is estimated to converge around 315 TWh/a, of which RES should cover approximately 47 %. This falls 3 percentage points short from the Government's target for 2030. Primary and final energy consumption in Basic scenario are presented in Table 2. As regards the targets on energy self-sufficiency, share of RES in the transport sector and halving the energy use of oil, Basic scenario falls short 4 percentage points, 20 percentage points and 12 TWh, respectively [16].

Table 2. Primary and final energy consumption in Basic scenario

Energy source	2015	2020	2030
Oil (including biofuels)	87	81	77
Coal	17	15	7
Coke, blast furnace gas and coke oven gas	12	16	18
Natural gas	22	27	22
Nuclear power	68	106	123
Net electricity import	16	3	2
Hydropower	17	14	15
Wind and solar power	2	5	7
Peat	15	20	15
Wood fuels	93	104	118
Other	14	16	18
Total primary energy consumption	361	408	420
Final energy consumption	297	313	316

Policy scenario

Policy scenario includes policy measures to achieve the aforementioned national targets set in the Strategy. As the EU 2020 targets are estimated to be achieved already during the current government term with the current trends, the focus will be in 2030 targets.

Some of the measures to reach the targets set in the Strategy are yet intangible and mentioned to be specified later on. However, some measures are described briefly in the Strategy, inter alia:

- Technology neutral tendering processes will be organised in 2018-2020 in order to increase RES utilisation in electricity production in the most cost-efficient way
- Increasing the obligation for the share of biofuels in road traffic to 30 %
- Coal will be phased out by taxation and subsidies for domestic substitutes in CHP production
- Investment support and tax exemptions for e.g. small-scale distributed energy generation
- Obligation to blend light fuel oil used in machinery and heating with 10 % of bioliquids

Primary and final energy consumption in Policy scenario are presented in Table 3.

Table 3. Primary and final energy consumption in Policy scenario

Energy source	2015	2020	2030
Oil (including biofuels)	87	79	73
Coal	17	15	3
Coke, blast furnace gas and coke oven gas	12	16	18
Natural gas	22	27	23
Nuclear power	68	106	123
Net electricity import	16	3	1
Hydropower	17	14	15
Wind and solar power	2	5	9
Peat	15	20	15
Wood fuels	93	104	121
Other	14	16	18
Total primary energy consumption	361	406	418
Final energy consumption	297	311	314

METHODS AND DATA

This chapter introduces the used simulation tool, EnergyPLAN, the applied stress test to the simulated energy systems and the more detailed assumptions regarding e.g. power capacities etc. in the analysed scenarios.

The authors have previously modelled the Finnish energy system in 2016 [8] on which the simulations in this paper are based. The simulated scenarios in different years are built to correspond with the assumptions and estimations provided in the background report of the Strategy [16].

EnergyPLAN

Energy system simulations in this paper are executed using a publicly available simulation tool, EnergyPLAN, which is developed and maintained by Sustainable Energy Planning Research Group at Aalborg University [17]. EnergyPLAN is a deterministic simulation tool, as opposed to optimisation models with an optimum solution. The tool simulates national energy systems on an hourly basis, including electricity, heating, cooling, transport and industry sectors. EnergyPLAN has been widely used for modelling systems with a high share of CHP production, e.g. [18], [19].

The Stress Test

Power capacity adequacy in the simulated scenarios is put under a stress test in years 2020 and 2030 by applying the implications of a severe drought in Finland during otherwise similar conditions as were witnessed during the demand peak in early 2016. The demand structure is assumed similar as during the peak and the level of electricity demand is scaled to match the estimations in the Strategy. External conditions, such as the share of available wind power production and availability of electricity imports, are also assumed similar. Nature of a severe drought in Finland is analysed in the following chapter.

Extreme drought

Hydropower production varies depending on the hydrological conditions. In recent years, the annual production of Finnish hydropower has on average been approximately 13 TWh, but varied between 9.3 and 16.5 TWh. During the last 100 years, the driest period in Finland occurred in 1939-1942, when the precipitation was below average for over three years. Year 1941 was the driest year in the 20th century with 34-45 % lower precipitation than on average. This resulted in record low discharges in rivers and water levels in lakes. The hydropower production was only around half of production in the late 1930s [20]. However, comparison of the hydropower production to present day is not possible, since most of Finland's hydropower capacity is built only after 1946.

To assess the implications of a drought with this severity to the energy system today, modelling of the 1939-1942 hydrology with the current hydropower capacity was carried out. Using observations of temperature, precipitation, wind speed and relative humidity of 1938-1942 provided by the Finnish Meteorological Institute, the discharge at current hydropower plants was modelled using Finnish Environment Institute's Watershed Simulation and Forecasting System (WSFS) [21]. The WSFS is a conceptual hydrological model used in Finland for operational flood forecasting and planning of hydropower production as well as research purposes including climate change impact assessment, e.g. [22]. Regulation of lakes was carried out in the WSFS following current regulation rules and practices. The WSFS was used to simulate average daily discharges of 57 largest hydropower plants in Finland (all plants with a capacity of 10 MW or more) and the discharges were used to estimate the average daily power production in 1939-1942.

In addition to the average daily power production, also the maximum power production during peak demand was estimated. Most of the hydropower plants are located at or downstream of regulated lakes allowing short-term increase in power production. The maximum hydropower production simulated for January 1942 (peak demand period) was estimated based on the regulation capacity of the power plants situated in lake outlets and in rivers downstream of them.

Basic Scenario

Assumptions regarding power capacity development in the scenarios are not described in detail in the Strategy, but the background report of the Strategy [16] presents estimates of available power capacities in Basic scenario during winter peaks in 2020 and 2030, which are depicted in Table 4. The estimations assume an availability of 6 % for wind power, but as the applied stress test assumes equivalent conditions as were experienced during the record-high demand peak in 2016, wind power availability is assumed 16 % of the installed capacity. As can be seen from the table, CHP district heating capacity will decrease notably by 2030. However, it is assumed that this does not affect the available heating capacity, as retiring CHP plants are replaced with heat-only boilers.

Table 4. Estimated available capacity during the winter peaks in 2020 and 2030 in Basic scenario

Production type	Available capacity during winter peak in 2020 (MW)	Available capacity during winter peak in 2030 (MW)
Hydro power	2,610	2,610
Nuclear power	4,380	5,130
Condensing power plants	725	725
Combined heat and power, total	5,395	5,000
CHP district heating	*3,115*	*2,545*
CHP industry	*2,280*	*2,455*
Wind power	320	385
Transmission capacity	4,800	6,000
Total	18,230	19,850

The background report also provides estimations on the magnitudes of the demand peaks in 2020 and 2030, which are approximately 15,440 MWh/h and 16,120 MWh/h, respectively.

Policy Scenario

Neither the Strategy nor its background report describe the development of power capacity in Policy scenario and, hence, the capacity is derived using the estimations of Basic scenario, annual energies in Policy scenario and other contents of the Strategy. As regards power capacity adequacy, no differences in Basic and Policy scenarios have yet emerged by 2020. However, it is assumed that currently the last commercially operative condensing coal plant, Meripori, is allocated in peak load reserves by 2030. Moreover, it is assumed that another 400 MW of district heating CHP capacity has been mothballed or allocated in reserves due to the phase-out of coal in energy production. Estimated available power capacities during winter peaks in 2020 and 2030 in Policy scenario are presented in Table 5.

Table 5. Estimated available capacity during the winter peaks in 2020 and 2030 in Policy scenario

Production type	Available capacity during winter peak in 2020 (MW)	Available capacity during winter peak in 2030 (MW)
Hydro power	2,610	2,610
Nuclear power	4,380	5,130
Condensing power plants	725	160
Combined heat and power, total	5,395	4,645
CHP district heating	*3,115*	*2,145*
CHP industry	*2,280*	*2,500*
Wind power	320	510
Transmission capacity	4,800	6,000
Total	18,230	19,055

Electricity consumption in Policy scenario is 1 TWh higher in 2030 than that in Basic scenario and the difference comes from industry, construction and transport sector. Assuming that the additional energy demand is divided evenly throughout the year, the demand peaks in 2020 and 2030 are 15,440 MWh/h and 16,225 MWh/h, respectively.

Alternative scenario

As Basic scenario is just one plausible projected energy market pathway, the authors wanted to analyse the aims of the Strategy with another pathway with alternative set of assumptions regarding especially the supply side.

Alternative scenario assumes a prolonged low level of electricity prices throughout the 2020s and hence a lack of willingness to invest in new power capacity. Most of the retiring CHP plants are replaced with heat only boilers due to the lack of economic feasibility of CHP electricity production and, moreover, Hanhikivi nuclear power plant investment does not realise. Neither Balticconnector nor growing LNG (liquefied natural gas) markets manage to restore the economic feasibility of natural gas and hence its utilisation keeps its declining trend. Moreover, investment in the third transmission line between northern Finland and Sweden does not realise. Meripori condensing coal power plant is allocated in peak load reserves starting from 2017 and it is assumed to stay in the reserves for the remainder of its technical lifetime. As regards electricity demand, electric vehicles have developed faster than predicted in the Strategy and there are already 500,000 electric vehicles in Finland by 2030, increasing the annual electricity demand by 1 TWh. The demand peaks in 2020 and 2030 are hence 15,440 MWh/h and 16,350 MWh/h, respectively. Estimated available power capacities during winter peaks in 2020 and 2030 in Policy scenario are presented in Table 6.

Table 6. Estimated available capacity during the winter peaks in 2020 and 2030 in Alternative scenario

Production type	Available capacity during winter peak in 2020 (MW)	Available capacity during winter peak in 2030 (MW)
Hydro power	2,610	2,610
Nuclear power	4,380	3,870
Condensing power plants	160	160
Combined heat and power, total	5,395	4,300
CHP district heating	*3,115*	*1,800*
CHP industry	*2,280*	*2,500*
Wind power	320	510
Transmission capacity	4,800	5,200
Total	17,665	16,650

SIMULATION RESULTS AND ANALYSIS

This chapter presents the results of the simulations. Moreover, impacts of climate change on the Finnish energy system are analysed.

Year 2020

As the Strategy was published in late 2016, no notable differences in Basic and Policy scenarios have yet occurred by 2020. Alternative scenario has 565 MW less capacity available during the winter peak due to Meripori condensing coal plant being allocated in peak load reserves, but the commercially available power capacity and transmission capacity during the peak demand still amount to more than 2,200 MW. Sum of the available commercial power capacity and available transmission capacity in different scenarios in 2020 and 2030 is shown in Table 7. All in all, capacity adequacy is much better in all scenarios comparing to that in 2016 [8] due to the expected completion of Olkiluoto 3 nuclear power plant.

As regards the implications of an extreme drought, the simulated hydropower availability is 790 MW lower than that estimated in the Strategy in both 2020 and 2030. This relatively modest (27 %) decrease is explained by the ability to use dammed storages during the peak demand. The annual hydropower production during the extreme drought decreases 43 % from long-term average production (7.5 TWh out of 13 TWh).

Year 2030

The simulations resulted in a notable improvement in power capacity adequacy in 2030 in Basic scenario, slight improvement in Policy scenario and an alarming drop in Alternative scenario. The difference between scenarios Basic and Policy is caused by the phase out of coal in energy use in Policy scenario and the assumption that most coal CHP plants are replaced with heat only boilers. Main reasons for the improved availability of capacity comes from investments in Hanhikivi nuclear power plant (1200 MW) and the two new transmission lines between Finland and Sweden (800 MW + 400 MW). Difference between scenarios Policy and Alternative come from the absence of Hanhikivi and the 800 MW transmission line between Finland and Sweden. Moreover, Alternative scenario assumes a stronger trend in replacing retiring CHP plants with heat only boilers. Available capacities in different scenarios during the winter peak in 2030 are shown in Table 7.

Table 7. Available production and transmission capacity during demand peaks in 2020 and 2030 in different scenarios

Scenario	Available capacity during the winter peak in 2020 (MW)	Available capacity during the winter peak in 2030 (MW)
Basic	2,790	3,730
Basic, Extreme drought	2,000	2,940
Policy	2,790	2,830
Policy, Extreme drought	2,000	2,040
Alternative	2,225	300
Alternative, Extreme drought	1,435	-490

Impacts of Climate Change on Finnish Climate and Energy System

Climate scenarios project a 1-3 °C increase in temperature by 2030 and modest increases (2-11 %) in precipitation in Finland [23]. Runoff is estimated to increase less than precipitation due to increase in evapotranspiration and runoff may even decrease in some scenarios. The seasonal variation of runoff will change with larger runoff in winter and less runoff during spring floods. For hydropower production, this means in most cases a more even distribution of discharges and less spill off, although in some cases changes in current regulation rules are needed to achieve the full benefits of this change. These changes in seasonal variation will on average mean increase in discharge during winter, when the peak demand occurs. Summer discharges will on average decrease. Moreover, extreme low temperatures causing the peak demand are expected to become less common with climate change [23].

These are, however, the changes in averages and changes in extremes, such as extreme drought, may be different. Some extreme weather events, such as heavy precipitation, are projected to become more common in future, but there is no clear evidence of changes in the probability of extreme drought in Finland [24].

DISCUSSION AND CONCLUSIONS

We have analysed the Finnish energy system and its plausible development in different energy policy scenarios and simulated hydropower availability during a year of severe drought in Finland. Moreover, we have simulated power capacity adequacy in the scenarios in years 2020 and 2030 with EnergyPLAN by applying the implications of a severe drought during otherwise equivalent conditions as were witnessed during the record-high demand peak in Finland in early 2016. Our results show that, in both of the scenarios presented in the new Energy and Climate Strategy of Finland, Basic and Policy, the stresses related to power capacity adequacy will ease comparing to those in 2016. This is mainly due to the two new nuclear power plants, Olkiluoto 3 and Hanhikivi, and the planned new transmission lines to Sweden, which together provide more capacity than the sum of estimated growth in the annual demand peak and reduction in thermal power capacity in Finland.

As regards Alternative scenario with no investments in Hanhikivi or to the third transmission line between northern Finland and Sweden, the issue is significantly more alarming. However, the estimated demand-side flexibility in the electricity spot market is currently approximately 400 MW and it is more likely to increase than decrease by 2030. Moreover, peak load reserves were increased from 300 MW in 2016 to over 700 MW for the period starting in June 2017 and it remains to be seen, how much of the retiring thermal capacity is allocated to some form of capacity reserves. Hence, also the energy system in Alternative scenario would have endured the stress test without resorting to e.g. rolling blackouts.

The current electricity price level in Finland does not encourage investments in new power capacity and, as electricity market price is practically determined by the short-term marginal costs of the last realised supply bid in the energy-only model, investments in wind or nuclear power are not about to increase the average price. Many utilities in Finland have already informed replacing retiring CHP plants with heat only boilers and the magnitude of this phenomenon is yet to be seen. CHP production has been a pride of the Finnish energy system due to its high thermal efficiency and hence it would not be surprising, if the government applied some incentives to keep it as a part of the system.

In spite of hydropower accounting for a notable share in power capacity and electricity production in Finland, an extreme drought has a relatively low impact on power capacity adequacy during winter peaks in Finland; dammed hydropower can be stored to be utilised during the winter peaks despite the annual energy production being much lower. However, Finland’s electricity markets are strongly affected by those of Sweden and Norway, which both have significantly higher shares of hydropower than Finland. Hence, as an extreme drought would be likely to occur in the Nordic countries and in western Russia simultaneously, the drought could affect the Finnish energy system more strongly via cross-border electricity trade. To understand the implications of a simultaneous severe drought in the Nordics and in western Russia, modelling of European power markets in a broader scale is needed, as the markets are growing more integrated by the year. This is a subject of future research. Moreover, EnergyPLAN functions better when simulating whether an energy system can supply its demand with the given deterministic input in a given year, but not so well for modelling the price formation and cross-border energy flows in a complex system of systems.

As regards the general impacts of climate change to the Finnish energy system, the simulated scenarios indicate that climate change could actually work in favour of power capacity adequacy by increasing the precipitation and discharges during the winter season and decreasing the occurrence of extremely low temperatures. However, climate change has had a tendency to increase the intensity of the extremes.

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NOMENCLATURE

CHP	combined heat and power
LNG	liquefied natural gas
RES	renewable energy source
SRC	Strategic Research Council
TSO	transmission system operator
WSFS	Finnish Environment Institute’s Watershed Simulation and Forecasting System

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