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Research article

Energy security impacts of a severe drought on the future Finnish energy system

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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 generation adequacy has grown more topical, especially since the record-high demand peak in Finland in January 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 plausible generation inadequacy. Moreover, as the Nordic energy system is so heavily dependent on hydropower production, we model and analyse the impacts of a severe drought on the Finnish energy system. We simulate hydropower availability according to the weather of the worst drought of the last century (in 1939–1942) with Finnish Environment Institute's Watershed Simulation and Forecasting System and we analyse the indirect impacts via reduced availability of electricity imports based on recent realised dry periods. Moreover, we analyse the environmental impacts of hydropower production during the drought and peak demand period and the impacts of climate change on generation adequacy in Finland. The results show that the scenarios of the new Energy and Climate Strategy result in an improved generation adequacy comparing to the current situation. However, a severe drought similar to that experienced in 1940s could cause a serious energy security threat.

1. Introduction

Energy security is a multidimensional and evolving concept. Moreover, it is increasingly popular as a research subject. A large body of research concentrates on defining and measuring energy security, e.g. (Ang et al., 2015) and (Månsson et al., 2014), but no academic consensus has been reached in either composing a clear definition or an indicator that would be useful for political decision-making. The latter is largely due to the lack of a money-metric translation between different dimensions of energy security (Böhringer and Bortolamedi, 2015). Therefore, it is sensible to take into account inter alia the unique geographical, political and economic environment of a nation and analyse energy security of the system per se instead of analysing the complex issue through an indicator.

In November 2016 Finland updated its National Energy and Climate Strategy (the Strategy), which includes targets on e.g. increasing the share of renewable energy sources (RES) by 2030. Concurrently, the issue of generation adequacy[1] during winter demand peaks has been present in the political discourse and in media especially since the record-high demand peak in early 2016 and the cautionary adequacy forecast in 2017 by The European Network of Transmission System Operators for Electricity (ENTSO-E) (ENTSO-E, 2017a). The authors have previously analysed the resilience of the Finnish power system in 2016 (Jääskeläinen et al., 2017; Jääskeläinen and Huhta, 2017) with the conclusion that the system still had enough generation capacity and measures of intervention to cope with severe unexpected faults. However, several simultaneous market trends amplify the stresses regarding security of supply, inter alia the increasing share of weather

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[1] Generation adequacy is defined here as the ability of the totality of generating units to meet demand at all times.

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dependent power production, prolonged low level of electricity market price and decreasing installed capacity of thermal power plants. Moreover, the national strategic objectives of further increasing the share of RES and phasing out coal in energy use both amplify the phenomenon. Thus, the issue of generation adequacy in the Finnish electricity market in the coming decades remains open for debate.

This paper analyses the development of generation adequacy in Finland until 2030 in the energy policy scenarios of the Strategy by modelling the implications of similar conditions as were experienced in early 2016 with the EnergyPLAN simulation tool. In addition to the scenarios in the Strategy, we analyse a third scenario with pessimistic Assumptions regarding investments in power plants and cross-border transmission lines. Moreover, as the Nordic energy system is so heavily dependent on hydropower production, we analyse the interdependence between hydrological situation in the Nordic countries and generation adequacy in Finland by applying the effects of a severe drought in the Nordic energy system in the analysed scenarios. In order to assess the implications of a severe drought on the Finnish energy system, we model the hydrology during the worst drought in the 20th century (1939–1942) with the current hydropower capacity using Finnish Environment Institute's Watershed Simulation and Forecasting System (WSFS). Furthermore, we briefly analyse the environmental impacts of hydropower operations during drought and peak demand in Finland.

Energy-water nexus and the environmental impacts of hydropower utilisation are widely studied research subjects, e.g. (Lam et al., 2016) and (Bakken et al., 2014), respectively. However, there are no extensive analyses on the impacts of a severe drought in the Nordics on generation adequacy in Finland and the environmental impacts of hydropower regulation during a drought. The novelty of this paper is in its interdisciplinary approach that combines hydrological simulations, energy system simulations, environmental assessment and energy policy analysis, and applies these to the official Finnish governmental energy and climate targets. Moreover, the energy-water nexus analysis is particularly interesting in the Nordics, as it is a multinational electricity market with hydropower in an exceptionally significant role.

First, section 2 introduces the current Finnish energy system, including the composition of electricity and heating markets, and the national energy policy targets. Section 3 presents the hydrological analysis and simulations and briefly analyses the impacts of climate change on hydropower availability in Finland. Section 4 introduces the energy system simulations including the input data, tools and results. Finally, section 5 draws conclusions.

2. The Finnish energy system

Due to its geographical location and energy-intensive industry, Finland's consumption per capita is high in both heat and electricity. Industry accounted for 45% of the final energy consumption in 2016 and other significant sectors were space heating (26%) and transport (17%) (Statistics Finland, 2017). Moreover, electricity and heating markets in Finland are linked via combined heat and power (CHP) production, which covers approximately 32% of Finnish electricity production and 67% of district heat production (Finnish Energy, 2017a). The most important primary energy sources in 2016 were biomass (25.9%), oil (23.2%) and uranium (18.2%) (Statistics Finland, 2017). Finland practically imports all of its fossil fuels and uranium, and a majority of the fuels are imported from Russia.

2.1. Electricity and heating markets

The Finnish electricity system is a part of the Nordic wholesale power market, Nord Pool, and hence connected with its neighbouring countries' power markets. Furthermore, Finland is heavily and increasingly dependent on cross-border electricity trade: net electricity imports covered 22.3% of the total electricity consumption in Finland in 2016 (Finnish Energy, 2017b), of which most was imported from Sweden. Therefore, the Finnish power system cannot be analysed in isolation from its neighbouring markets. The main connections are with Sweden, Estonia and Russia, of which the two former are included in the common electricity market. In total, the cross-border transmission capacity allows Finland to import approximately 5100 MW of power from its neighbouring countries, which is more than one third of the record-high hourly demand peak. Moreover, the Strategy includes plans to further increase the transmission capacity between Finland and Sweden in the 2020s, and concrete preparations for a third AC connection started in December 2016.

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% (Statistics Finland, 2017). Total installed power capacity in Finland amounted to approximately 16,100 MW in early 2016 (Finnish Energy Authority, 2017). However, as some of the capacity is allocated as system reserves, some is mothballed 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, total installed power capacity and the Finnish transmission system operator's (Fingrid) estimation of the available power capacity during the demand peak in 2016 (Statistics Finland, 2017) are presented in Table 1.

Electricity demand in Finland has not increased during the 2010s, but has remained at 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 competitiveness. Consequently, the commercially active condensing power capacity in Finland has decreased by more than 2000 MW since 2010. The last commercially operative condensing coal plant was partly allocated in the peak load reserves in July 2017 and others have been mothballed or decommissioned earlier. Wind power capacity in Finland and in the Nordics has been growing rapidly – mainly due to national subsidy mechanisms. Wind power capacity in Finland grew from approximately 1000 MW in early 2016 to 2044 MW by the end of 2017 under the current feed-in tariff mechanism. Moreover, wind power capacity in Sweden has experienced similar trends with a greater magnitude, which affects the Finnish power market via availability of electricity imports and their price level.

Due to its geographical location, Finland has a high demand for heat especially during the winter period. A major share of the heating in larger cities is supplied with CHP production whereas a combination of electrical heating, small-scale wood combustion and heat pumps is typically used in remote areas. In comparison with the electricity market, heating market in Finland is much more scattered. Moreover, it is less sensitive with regard to 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. Therefore, generation adequacy in heating networks has not been an issue and the focus of the analysis is in the electricity market.