Adequacy of Power Capacity during Winter Peaks in Finland

Jaakko Jääskeläinen, Behnam Zakeri, Sanna Syri
Aalto University, School of Engineering
Department of Mechanical Engineering
P.O. Box 14100, FIN-00076 Aalto, Finland
jaakko.j.jaaskelainen@aalto.fi

***Abstract*—Due to ambitious national and EU level climate targets, wind power capacity in Finland has grown rapidly, while a significant amount of thermal capacity has been decommissioned or mothballed. Moreover, Finland is growing more dependent on electricity imports and the current electricity prices do not encourage market-based investments in power capacity. Hence, the issue of power capacity adequacy during winter peaks has been present in the political discourse in Finland, especially since the record-high demand peak in January 7th 2016. We analyse the Finnish power system by simulating different stress factors and their combinations, e.g. faults in the largest power plants and transmission lines, in a period such as January 7th 2016 using EnergyPLAN simulation tool. The results show that, despite the record-high demand, the Finnish power system currently has both technical capacity and adequate measures of intervention to cope with severe stress factors in the simulated period.**

Keywords—capacity adequacy, energy security, energy system modelling

I. Introduction

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 in future scenarios, e.g. the relation between increasing the share of renewable energy sources (RES) and system stability, i.a. [5], [6]. However, very little, if any, research has been made in order to map the power capacity adequacy of an existing electricity system – at least in case of Finland.

The issue of power capacity adequacy in Nord Pool region during winter peaks has grown more topical and important during the past years. The issue has especially been present in the political discourse and in media since the record-high demand peaks in Finland (15,105 MWh/h, 7.1.2016) and in the Nordics (70,159 MWh/h, 21.1.2016) [7]. Moreover, due to European power market integration [8] and ambitious EU level RES targets [9], capacity adequacy will most probably not remain as a Nordic issue.

During the peak demand hour in January, Finland imported approximately 4,230 MWh [10] of electricity from its neighbouring countries and, consequently, no shortages in power supply were experienced. Moreover, the Transmission System Operator (TSO) of Finland, Fingrid, did not have to resort to any capacity reserves and even the electricity market price in Finland remained moderate, under 100 EUR/MWh. The aim of this paper is to put the Finnish electricity system under scrutiny and analyse the impact of different stress factors in the system in a period such as week 1 of 2016 using EnergyPLAN simulation tool. This analysis is a part of Winland project, which aims to assess comprehensively threats related to food, water and energy supply in Finland and ways to improve resilience against external shocks.

Firstly, Chapter II introduces the Finnish electricity system and circumstances during the record-high demand peak in 7.1.2016. Moreover, we briefly analyse the current trends in the power market. Secondly, Chapter III reviews the used simulation tool, EnergyPLAN, and input data for the modelling. Thirdly, Chapter IV presents the applied stress factors in the power system during the peak load situation and the simulation results. Finally, we analyse the results in Chapter V.

II. The Finnish Electricity System

A. General

The Finnish electricity system has two noteworthy characteristics: firstly, it 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]. 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.

978-1-5090-5499-2/17/$31.00 ©2017 IEEE

Secondly, due to its geographical location and high share of energy-intensive industry, Finland's consumption per capita is high in both heat and electricity. Moreover, electricity and heating markets in Finland are strongly coupled via combined heat and power (CHP) production, which covers a major share of the Finnish energy production. This needs to be taken into consideration when analysing the Finnish power system.

B. *Supply and Demand*

The Finnish electricity generation mix is highly diversified, comprising high shares of nuclear, hydro and thermal power production and an increasing share of wind power production. Electricity supply of 2016 (85.1 TWh in total) by sources is presented in Table I [11].

Table I. Finnish energy consumption in 2016.

Production type	**Consumption (TWh/a)**	**Share (%)**
Hydropower	15.6	18.3
Nuclear power	22.3	26.2
Condensing power plants	4.4	5.2
Combined heat and power, total	20.8	24.4
CHP district heating	*11.8*	*13.8*
CHP industry	*9.0*	*10.6*
Wind power	3.1	3.6
Net import	19.0	22.3
Total	**85.1**	**100.0**

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 interesting figure is the estimated available capacity during the demand peak. Total installed capacity [12], Fingrid's estimation of the available power capacity during the demand peak in 2016 [13] and the actual realised production during the peak in 7.1.2016 are presented in Table II.

Table II. Installed power capacity, estimated available capacity during the peak in 2016 and actual production in the peak of 2016 in Finland.

Production type	**Installed capacity (MWe)**	**Estimated available capacity during the peak (MWe)**	**Production during the peak (MWe)**
Hydropower	3,180	2,550	2,235
Nuclear power	2,780	2,780	2,776
Condensing power plants	2,160	960	638
Combined heat and power, total	6,985	5,250	4,790
CHP district heating	4,170	3,250	3,134
CHP industry	2,815	2,000	1,656
Wind power	1,005	60	161
Other	-	-	274
Total	**16,110**	**11,600**	**10,874**

The realised production during the peak is based on Fingrid's estimation and the production referred to as *Other* is production that has not been managed to specify. We allocate the *Other* production under condensing production in Fig 1, as e.g. Pöyry [14] estimates that Finnish district heating CHP plants are able to produce approximately 210 MW of electricity in a condensing mode during the peak demand. The estimated condensing power capacity during the peak (960 MW) hence includes the aforementioned 210 MW, as Pöyry's estimate of Finnish condensing capacity is correspondingly 750 MW. As regards market based demand flexibility, there are not much data available, as Nord Pool does not publish electricity market supply and demand curves. However, Fingrid estimates the flexible demand in the day-ahead market to be between 200 and 600 MW in 2016 [15]. Hence, we assume the unused demand flexibility to have been 400 MW during the demand peak in 7.1.2016 in this study.

C. *Demand peak in January 7th 2016*

The Finnish power system witnessed a record-high demand for electricity in the first week of January in 2016, which culminated in a record-high hourly consumption peak, 15,105 MWh/h, in 7.1.2016 between hours 17 and 18. The consumption-weighted outside temperature during the peak was -25°C [10]. Demand during the peak surpassed the estimated available power capacity in Finland by more than 3,500 MW and, consequently, approximately 4,230 MWh of electricity was imported during the hour [10]. However, despite the record-high demand, no shortages in power supply were experienced. Moreover, Fingrid did not have to resort to any capacity reserves and even the electricity spot price in Finland remained moderate, at 99.94 EUR/MWh [7].

Despite the relatively low wind power production during the peak, market conditions were generally favourable: in addition to the lack of disturbances in the power system during the peak, there was a national holiday in Russia, which ensured the abundancy of electricity imports from Russia at a moderate price level. Moreover, hydro reservoir levels were higher than on average in early 2016 [16]. Electricity consumption of Finland in 7.1.2016 is illustrated in Fig 1.

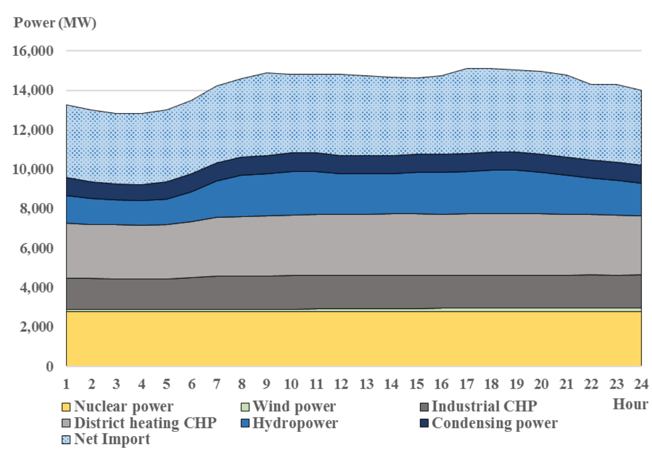

Figure 1. Electricity supply and demand in Finland in 7.1.2016.

Electricity supply from the peak demand hour is shown in Table II. It should be noted that wind power production was rather low during the peak, but on the other hand, higher wind speeds also increase the heating demand and hence the amplitude of the demand peak.

EL-TRAN [17] analysed the structure of the power demand during the peak with several findings; firstly, industrial electricity use does not explain the peak, as industrial power demand matched the annual average consumption during the peak. Thus, more than two thirds of the demand comes from households. Secondly, even though electricity demand in households is monotonously increasing with falling outside temperature, no institution in Finland understands the detailed composition of the demand during the peak. However, it is estimated that 1°C drop in outside temperature results in approximately 100-200 MW of additional electricity demand in Finland, which is partly caused by the increasing demand for heat and partly by the decreasing efficiency of heat pumps. Moreover, EL-TRAN estimates that additional electrical heaters might explain up to 1000 MW of the demand during the peak.

D. Maintaining Power Capacity Adequacy in Finland

To maintain the system security, the Finnish and Nordic power systems use the N-1 criterion, i.e. the systems are built to withstand the most common individual faults in power production and transmission. After responding to a fault in the system, Fingrid strives to restore the readiness to respond to the next possible fault as quickly as possible. Moreover, Fingrid and Nord Pool have a variety of instruments in order to maintain adequate power capacity in Finland in case the markets fail to solve the situation. Firstly, in case an intersection between supply and demand curves is not achieved after the market based demand flexibility, Nord Pool would effectuate one or more of the following measures [18]:

- Activate peak load reserves
- Ask the TSO about the possibility to adjust the trading capacity
- Block orders that increase curtailment
- Deduct orders on a pro rata basis until a point of intersection is achieved

The peak load reserves are offered to Elspot market, if supply and demand curves do not intersect otherwise. Capacity reserve for the period 1.7.2015-30.6.2017 is approximately 300 MW and it comprises Naistenlahti 1 and Haapavesi power plants and Suomenoja heat pump as demand response. The two power plants are on a 12-hour readiness during the winter period. However, since 2010 there has been no need to activate the peak load reserves [19].

Fingrid, on the other hand, controls different frequency restoration reserves, which comprise approximately 1000 MW of reserve capacity with a starting time of 10-15 minutes [17]. These reserves are mainly fuel oil powered gas turbine power plants. However, as mentioned earlier, the primary function of the frequency reserves is to cope with unexpected faults in the power system and they operate completely outside the Elspot market. Different frequency restoration products and their capacity obligations are presented in Table III.

Table III. Fingrid's frequency containment and restoration reserves.

Reserve product	**Obligation (MW)**
Frequency Containment Reserve for Normal operation (FCR-N)	about 140
Frequency Containment Reserve for Disturbances (FCR-D)	220-265
Automatic Frequency Restoration Reserve (aFRR)	70
Manual Frequency Restoration Reserve (mFRR)	880-1100

In addition to operating the frequency reserves, Fingrid coordinates the communication between different power market stakeholders, ensures that all available capacity is activated in case of power supply shortage and blocks bids in the Elbas market or the whole market, if needed [20]. If demand for electricity is not met with all the aforementioned instruments, Fingrid will apply rolling blackouts in the Finnish power system. However, this procedure has yet to be tested. Mainly due to the high hydropower capacity in Norway and Sweden, the Nordic electricity markets have traditionally had no major problems as regards system balance and capacity adequacy during winter peaks. However, the current trends are leading to possible difficulties, which we will discuss in the following chapter.

E. Current Trends

Demand for electricity 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. Furthermore, the lower demand has significantly reduced the 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 2,000 MW since 2010. Currently there is only one condensing coal plant in Finland in commercial operation, whereas others have been mothballed or decommissioned. Condensing power has traditionally been the price setter in the day-ahead market and it 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 schemes. Wind power capacity in Finland was approximately 1,005 MW in early 2016 and it is expected to double by the end of 2017 under the current feed-in tariff mechanism [14].

The two aforementioned trends, decreasing thermal power capacity and increasing wind power capacity, are most likely set to continue. The Finnish Government published a new National Energy and Climate Strategy in 24.11.2016, which presents a roadmap to achieve the national targets on i.a. increasing the share of RES and cessation of coal use in energy production. However, there is a 1,600 MW nuclear power plant, Olkiluoto 3 (OL3), being built in Finland, which is estimated to start its operation in late 2018. OL3 should reduce the stresses related to power capacity adequacy starting from 2019, but the issue of capacity adequacy remains highly topical at least in 2017-2018.

III. Methods and Data

A. EnergyPLAN

The power 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 [21]. 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. Even though the electricity system is the most sensitive in terms of system stability and the magnitude of possible risks, inclusion of heating sector is essential in the Finnish energy system, as heat and power markets are strongly coupled via CHP production in Finland. However, EnergyPLAN has been widely used for modelling systems with a high share of CHP production, e.g. [22], [23].

EnergyPLAN has two different simulation strategies: technical and market economic. The technical simulation prioritises all domestic production in the dispatch order before importing any electricity, whereas the market economic simulation reflects the dynamics of Nord Pool day-ahead market more accurately, prioritising imported electricity in case its price is lower than the short-run marginal costs of domestic production. Moreover, the market economic simulation reflects the nature of hydropower in a liberalised electricity market as a market-balancing instrument more accurately and, hence, simulations in this study utilise the market economic scheme.

B. *Input Data for EnergyPLAN*

Power plants and their capacities are based on Finnish Energy Authority's power plant register, in which all power plants in Finland with at least one MVA of capacity are registered [12]. Data on transmission lines to neighbouring countries [24] and the estimated available capacities during demand peaks come from Fingrid.

Inflexible power production methods maintain a major part of the demand. This comprises e.g. nuclear baseload, wind power and run-of-river hydro. Moreover, industrial CHP power production is given as an inflexible input and the simulated scenarios assume the actual realised production in early 2016. Hourly distributions for inflexible data are based on data collected by Fingrid [25]. Annual heating demand on an hourly basis is estimated based on the district heating CHP electricity production. Electricity day-ahead market prices and hydro reservoir levels are publicly available data in Nord Pool website [7]. Cost data for power plants is based on Energienet.dk's report Technology Data for Energy Plants [26]. The EnergyPLAN model used in this study is calibrated so that the actual electricity market conditions during the first week of January 2016 are reflected as accurately as possible.

IV. Analysis and Simulation Results

A. *Analysed Stress Factors in the Power System*

This chapter discusses the risk factors that could have realised in early 2016. Moreover, as the Finnish energy system is prepared for any single component in the system to fail (N-1 criterion), this study analyses the needed combinations of such stress factors that would eventually have caused major problems in the system upon realisation.

As regards faults in power production, the biggest power plants in Finland are currently nuclear power units Olkiluoto 1 (OL1) and Olkiluoto 2 (OL2), each of them having an electrical capacity of 880 MW. Therefore, forced outages in OL1 and OL2 are analysed in this study. As regards transmission lines, the biggest single connection is an AC line between Finland and SE1 (northern Sweden), in which a fault can cause a loss of up to 1,100 MW of transmission capacity. Moreover, a failure in DC line Fennoskan 2, of whose failure would reduce the power supply by 800 MW, is analysed. Analysed stress factors are listed in Table IV.

Table IV. Simulated stress factors in the power system.

Stress factors [Fn]	**Effect on Power Availability (MWe)**	**Probability of forced outage (%)**
F_1. SE1-FI Transmission line forced outage	1,100	2 [14]
F_2. Olkiluoto 1 forced outage	880	2.1 [27]
F_3. Olkiluoto 2 forced outage	880	2.1 [27]
F_4. Fennoskan 2 forced outage	800	6 [14]

B. *Simulated Scenarios*

This chapter presents the results of the EnergyPLAN simulations in different scenarios. The simulations present scenarios where no measures of intervention to improve capacity adequacy have been taken. Implications and measures of the scenarios are analysed and discussed in Chapter V.

1) *Scenario 1*

Scenario 1 simulates a similar market situation as the first week of 2016, where the SE1-FI transmission line (F_1) has been damaged before the peak demand day. Hence, lack of the transmission capacity is already included in the aggregated supply curve in the day-ahead trade. As can be seen from Fig 2, the power system has enough installed power capacity and available transmission capacity to supply the demand without any measures of intervention.

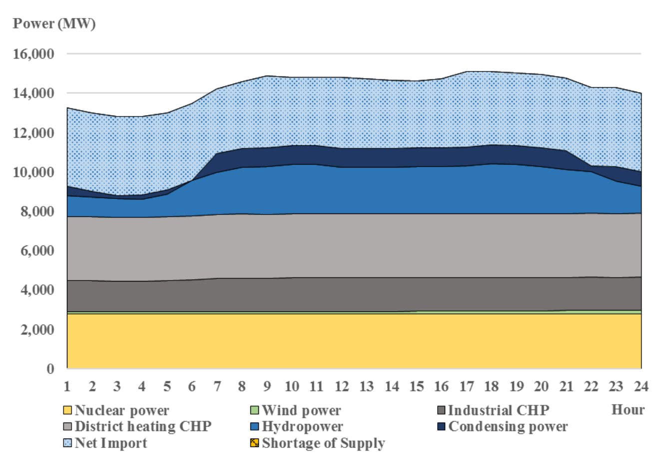

Figure 2. Electricity supply in Scenario 1.

2) *Scenario 2*

Scenario 2 simulates simultaneous forced outages in SE1-FI transmission line (F_1) and OL1 power plant (F_2) during a market situation such as the first week of 2016. Again, the stress factors have realised separately before the peak demand day and measures to deal with the short-term effects have been taken. Hence, the lack of capacity is already included in the day-ahead trade for the peak demand day in 7.1.2016. As can be seen from Fig 3, there is a shortage of supply throughout the day. The highest lack of capacity is between hours 17 and 18 and it is approximately 700 MW.

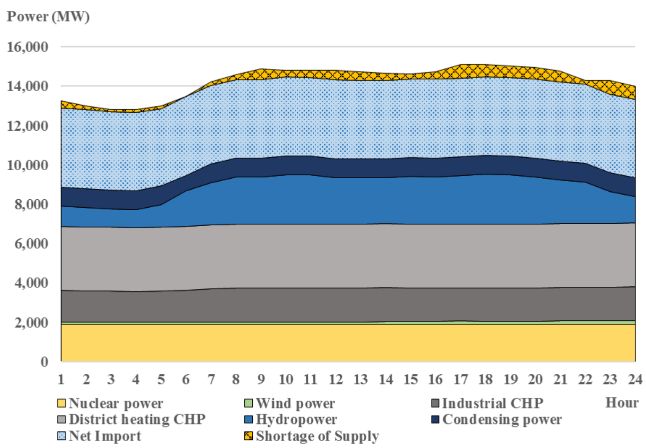

Figure 3. Electricity supply in Scenario 2.

3) *Scenario 3*

Scenario 3 simulates simultaneous forced outages in OL1 (F_2) and OL2 (F_3) and a fault in Fennoskan 2 (F_4) during a market situation such as the first week of 2016. Again, the stress factors have realised separately before the peak demand day and measures to deal with the short-term effects have been taken. Hence, the lack of capacity is included in the day-ahead trade for the peak demand day in 7.1.2016. As can be seen from Fig 4, there is a severe shortage of supply throughout the day. The highest lack of capacity is between hours 17 and 18 and it is approximately 1,280 MW.

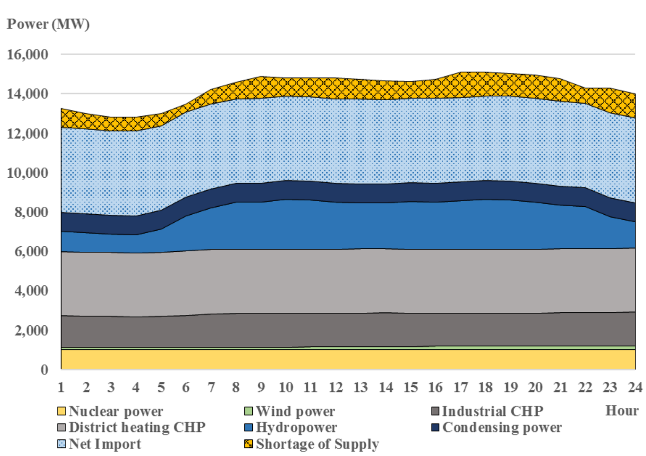

Figure 4. Electricity supply in Scenario 3.

V. DISCUSSION AND CONCLUSIONS

We have analysed the Finnish power system and conditions during the record-high demand peak in 7.1.2016 and, moreover, identified some of the most severe plausible stress factors that could have realised in early 2016. Furthermore, we have used EnergyPLAN simulation tool to assess the implications of such factors in the power system during a similar demand peak period. Our simulations show the resulting shortage of supply in the scenarios assuming a *ceteris paribus* situation. However, there is a variety of responses from the markets and measures of intervention that would be taken before letting a full-fledged blackout realise, which we will discuss in this chapter.

Scenario 1 simulated a situation, where the single largest power source in the system is unavailable. Despite the record-high demand, the day-ahead markets had sufficient amount of capacity to supply the demand. Moreover, a fault in SE1-FI transmission line would have moved the point of intersection between supply and demand curves, increased the electricity market price and, hence, mitigated the stress by lowering the demand. As regards the short-term effects of an abrupt fault of this magnitude in the system, Fingrid would have needed to activate frequency restoration reserves to maintain or restore the system stability. The probability of Scenario 1 to have been realised during the demand peak is approximately 2 %.

The highest lack of power capacity in Scenario 2 is 700 MW, which by coincidence corresponds to the sum of available peak load reserves and the estimated demand flexibility. However, this situation already reflects a very high stress in the power system and the activation of peak load reserves implies that there are no more market based supply bids in the electricity market. Hence, the day-ahead market price could reach the ceiling price, 3,000 EUR/MWh, which is approximately hundred times the average price in the Elspot market. As F_1 and F_2 are not interdependent, the probability of Scenario 2 to have been realised during the demand peak is approximately 0.042 %.

Scenario 3 reflects a severe and unlikely situation of three major power system components failing during a record-high demand peak. After demand flexibility and activation of the peak load reserves, there would still have been a shortage of 580 MW during the highest peak and, hence, Nord Pool would have had to cut the demand curve. This situation has yet to realise in Finland and the detailed procedures are hence to be tested. However, Fingrid has sufficient reserves to supply the demand, but it is a matter of prioritising, whether the reserves are held up for yet another fault in the system. Moreover, a shortage of supply with this severity would have been reflected with the ceiling price in the electricity market throughout the day, which could have encouraged a demand response higher than the estimated 400 MW. The estimation applies in short-term situations, whereas electricity price futures indicating prolonged elevated market prices could encourage higher amount of flexibility in e.g. industrial electricity use. As F_2, F_3 and F_4 are not interdependent, the probability of Scenario 3 to have been realised during the demand peak is approximately 0.0026 %.

Altogether, despite the raised awareness in power capacity adequacy in Finland, the simulations indicate that the situation in the Finnish electricity market was not yet utterly grave in early 2016. Considering the unused transmission capacity, estimated demand flexibility, peak load reserves, unused hydropower and industrial CHP capacity and Fingrid's reserves, there was technically still approximately 3,200 MW of available capacity during the peak in 7.1.2016. However, Finland does rely heavily and increasingly on electricity imports, which is mostly explained via lower short-term marginal costs of electricity production especially in Sweden. Therefore, the issue is currently of a political nature, i.e., how great a threat the lack of self-sufficiency in energy supply is considered in Finland and, moreover, how much Finland is willing to pay for self-sufficiency. Despite the trends of growing amount of variable RES capacity and decreasing thermal capacity, OL3 should reduce the stresses related to capacity adequacy and import dependency in Finland. However, if electricity futures keep indicating low enough electricity market prices, retiring CHP plants could be replaced with heat-only boilers in the following decades, which would again amplify the stresses related to power capacity adequacy in Finland.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the contributions of Strategic Research Council (SRC) by funding this research through the Winland project. Moreover, the authors are grateful for the valuable input provided by experts from Fingrid and SKM Market Predictor AS, Risto Kuusi and Riku Merikoski, respectively.

REFERENCES

[1] E. Kiriyama and Y. Kajikawa, "A multilayered analysis of energy security research and the energy supply process", Applied Energy 123 (2014) 415-423

[2] A. Månsson, B. Johansson and L. J. Nilsson, "Assessing energy security: An overview of commonly used methodologies", Energy 73 (2014) 1-14

[3] B.W. Ang, W.L. Choong and T.S. Ng, "Energy security: Definitions, dimensions and indexes", Renewable and Sustainable Energy Reviews 42 (2015) 1077-1093

[4] J. Ren and B. K. Sovacool, "Quantifying, measuring, and strategizing energy security: Determining the most meaningful dimensions and metrics", Energy 76 (2014) 838-849

[5] J. N. V. Lucas, G. E. Francés and E. S. M. González, "Energy security and renewable energy deployment in the EU: *Liaisons Dangereuses* or Virtuous Circle?", Renewable and Sustainable Energy Reviews 62 (2016) 1032-1046

[6] D. K. Jonsson, B. Johansson, A. Månsson, L. J. Nilsson, M. Nilsson, H. Sonnsjö, "Energy security matters in the EU Energy Roadmap", Energy Strategy Reviews 6 (2015) 48-56

[7] Nord Pool, Power system data, [Online]. Available: www.nordpoolspot.com [Accessed 1.11.2016]

[8] European Commission, A fully-integrated internal energy market, [Online]. Available: https://ec.europa.eu/priorities/energy-union-and-climate/fully-integrated-internal-energy-market_en [Accessed 26.1.2017]

[9] European Commission, Renewable energy targets for 2020 and 2030, [Online]. Available: https://ec.europa.eu/energy/en/topics/renewable-energy [Accessed 26.1.2017]

[10] Fingrid, "Power Capacity in the Nordics", Presentation by the President and CEO, Jukka Ruusunen, March 2016, Available: http://www.fingrid.fi/fi/asiakkaat/asiakasliitteet/Neuvottelukunta/2016/21.3.2016/WEC%20Power%20Capacity%20in%20the%20Nordics.pdf [Accessed 10.11.2016]

[11] Finnish Energy, Summary of Energy year 2016 in Finland, [Online]. Available: http://energia.fi/ajankohtaista_ja_materiaalipankki/materiaalipankki/energiavuosi_2016_sahko_sahkonkaytto_kaantyi_nousuun.html#material-view [Accessed 1.2.2017]

[12] Energy Authority, Power plant register, [Online]. Available: https://www.energiavirasto.fi/web/energy-authority/power-plant-register [Accessed 20.1.2017]

[13] Statistics Finland, Energy statistics, [Online]. Available: http://pxweb2.stat.fi/sahkoiset_julkaisut/energia2015/html/engl0000.htm [Accessed 20.12.2016]

[14] Pöyry, "The required peak load reserves for 2017-2022", 20.9.2016, [Online]. Available: https://www.energiavirasto.fi/documents/10191/0/EV_Tehoreservin+m%C3%A4%C3%A4r%C3%A4%202017-2022_Loppuraportti.pdf/8eca5950-0b8f-429e-a27e-23f77cae5da4

[15] Fingrid, Demand side management, [Online]. Available: http://www.fingrid.fi/en/electricity-market/Demand-Side_Management/Pages/default.aspx [Accessed 20.1.2017]

[16] Nord Pool, Hydro reservoir data, [Online]. Available: http://wwwdynamic.nordpoolspot.com/marketinfo/rescontent/area/rescontent.cgi [Accessed 1.2.2017]

[17] EL-TRAN, "The demand peak in January – what happened in 7.1.2016? How will power be managed better in the future?", [Online]. Available: https://tt.eduuni.fi/sites/EL-TRAN/Julkiset%20tiedostot/Juhani%20Heljo%20et%20al.,%20Tammikuun%20tehopiikki%20-%20mit%C3%A4%20tapahtui%207.1.2016,%20miten%20tehoa%20hallitaan%20paremmin%20jatkossa.pdf

[18] Nord Pool, Procedures in case of non-matching, [Online]. Available: http://nordpoolgroup.com/globalassets/download-center/rules-and-regulations/nordic-baltic-rulebook-march-2016/trading-appendix-2a.-elspot-market-regulation-with-new-products-16.03.2016-original.pdf [Accessed 1.2.2017]

[19] Energy Authority, Peak Load Reserve for the period 1.7.2015-30.6.2017, [Online]. Available: https://www.energiavirasto.fi/documents/10179/0/Peak+load+capacity+reserve+system-+Procurement+decision+-Summary.pdf/28083f10-0406-4b9e-bf64-4bc7b60757c0 [Accessed 17.1.2017]

[20] Fingrid, Procedures in case a shortage of power supply, [Online]. Available: http://www.fingrid.fi/fi/voimajarjestelma/voimajarjestelmaliitteet/Voimaj%C3%A4rjestelm%C3%A4n%20hallinta/K%C3%A4ytt%C3%B6varmuuden%20yll%C3%A4pito/tehopulatilanteiden%20hallinta%202017.pdf [Accessed 17.1.2017]

[21] EnergyPLAN, [Online]. Available: http://www.energyplan.eu/

[22] R. Lund and B. V. Mathiesen, "Large combined heat and power plants in sustainable energy systems", Applied Energy 142 (2015) 389–395

[23] B. Zakeri, S. Syri and S. Rinne, "Higher renewable energy integration into the existing energy system of Finland - Is there any maximum limit?", Energy 92 (2015) 244-259

[24] Fingrid, Nordic power system interconnections, [Online]. Available: http://www.fingrid.fi/en/powersystem/general%20description/Nordic%20power%20system%20and%20interconnections%20with%20other%20systems/Pages/default.aspx [Accessed 20.1.2017]

[25] Fingrid, State of the power system, [Online]. Available: http://www.fingrid.fi/en/electricity-market/power-system/Pages/default.aspx [Accessed 1.11.2016]

[26] Energinet.dk, Technology data for power plants, May 2012, [Online]. Available: https://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Forskning/Technology_data_for_energy_plants.pdf

[27] Technical Research Center of Finland, A study on needed peak load reserves for 2015-2020, [Online]. Available: http://www.vtt.fi/inf/julkaisut/muut/2014/VTT-R-06032-14.pdf