Day-ahead Electricity Market Estimation of Finland in 2030

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Abstract

The European Green Deal targets to increase significantly the share of renewable energy sources (RES) in the electricity system by 2030. However, the electricity market is a competed sector and the private investors develop RES capacity based on the profitability of the business plan. The RES profitability depends strongly on the long-term future price of the electricity market, which needs to be estimated. Although several studies focus on developing accurate short-time forecasting methods for the day-ahead market, these methods cannot be used for long-term forecasting due to uncertainty of the required inputs, e.g. weather condition and fuel cost, in a long-term future. In these circumstances, this paper developed a methodology to analyse and estimate the long-term day-ahead electricity market. This research used the data of Finnish electricity market to show the performance of the methodology. However, the same methodology could also be applied to other countries.

1 Introduction

According to the Finnish national energy and climate plan (NECP), Finland aims to achieve carbon neutrality by 2035 and carbon negativity soon after that. In this regard, the government program states that the electricity and heat production in Finland must be made nearly emissions-free by the end of the 2030s. To achieve this, the share of renewable energy sources (RES) in electrical consumption must be reached to 53% by 2030 [1].

Currently, the main RES sources in the Finnish electrical system are hydropower, biomass, wind power, and photovoltaic (PV) panels. The inner plot of Fig.1 shows the total electricity production (TWh) of different RES technologies in Finland in 2018 [1]. By analysing the total profiles of the electricity demand in Finland, NECP [1] estimates that the wind power capacity and PV panels capacity increased respectively to 5500 MW and 1200 MW in 2030, 2.7 and 10 times larger than the installed capacity at the end of 2018. However, the hydropower will not grow since there is no available resource anymore. The outer plot of Fig. 1 shows the estimation of RES productions in 2030. In addition, the Finnish transmission system operator, Fingrid, estimates demand growth between 10% to 20% for 2030 in comparing to 2018, which was about 87 TWh. [2].

Although the Finnish government planned to increase the penetration level of RES, the electricity market is a competed sector. It means that the private investors develop RES capacity based on the profitability of the business plan, which depends on the electricity market price. On the other hand, the amount of RES production affects the electricity market price and accordingly the return rate of the investment in the RES. Consequently, it is of prime importance to analyse the influence of RES penetration in the day-ahead electricity market and estimate the market price in future years.

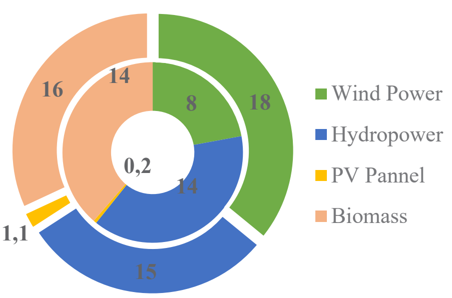

Fig. 1. The total electricity production (TWh) of different RES of Finland in 2018 and 2030 (estimation) [1],

2 State of the Art

There is plenty of methods used to forecast the day-ahead electricity market. A good survey of recent works in this area can be found in [3]. In general, these methods can be divided into two main categories. (1) Statistical methods relying on historical values regardless of the market structure, e.g. comprising time series and artificial intelligence-based models. For example, methods based on a deep neural network and a recurrent neural network are developed respectively in [4] and [5]. (2) Methods simulating the operation of market players and predicting their behaviour using the forecasted future inputs, e.g. multi-agent methods.

For instance, an agent-based model to study the impact of changing energy policy on the electricity market is developed in [6].

Most of the abovementioned research aims to provide the short-term forecast of the day-ahead market price as accurate as possible to optimise the bidding strategy of market actors. To the best of authors' knowledge, and according to the survey in [3], methods for long-term forecasting of electricity price are rare. However, as explained in Section 1, the long-term forecasting of the electricity market is very critical to decide wisely for investing in RES. A few research focus on longer-term forecasting, e.g. forecasting the price spike in [7] or average price in [3] in the next three years.

In order to employ the existing forecasting methods in a long-term forecast, e.g. 10 years, it is required to estimate several variables, e.g. weather condition, fuel cost, and emission allowance, as inputs. However, the estimation of these inputs for a long-term includes significant uncertainty. Therefore, this research proposes to use a simplified model, which does not need several inputs. In this regard, first, a simplified market structure is estimated using historical data and then it is expanded using the merit order effect [8] to consider the impact of new productions and demand growth in the future. The next section describes this methodology.

3 Long-term market Forecasting

3-1 Day-ahead Market Mechanism

In the day-ahead market, which trades the majority of the electricity, the hourly price is determined using the intersection of demand and supply curves, resulting from the bidding process for each hour [8]. Fig. 2 shows a schematic of the supply and demand curves for an arbitrary hour. It is worth mentioning that the elasticity of demand to the price in a short time is much less than what shown in Fig. 2. Although this figure is used here to illustrate the methodology, in the future, when more smart energy management systems are used, the demand curve could respond rapidly as shown in Fig. 2 [9].

In this type of markets, one energy producer does not have the power to change the market price, Therefore, the energy producers participate in the electricity market according to their marginal cost (MC) to maximise their profit [8]. In these circumstances, the energy producers can be divided into two categories: price-maker and price-taker. The latter type of energy producers are willing to sell their productions regardless of the energy price. The reason is either they have approximately zero marginal cost, e.g., RES, or high start-up cost, e.g., nuclear power plant (NPP). Therefore, price-taker producers usually bid with close to zero MC in the market. In these circumstances, their impact on the market can be modelled by a horizontal shift in the supply curve, which is called the merit order effect [9]. Fig 2 illustrates the merit order effect. The black dash line in Fig.2 shows the supply

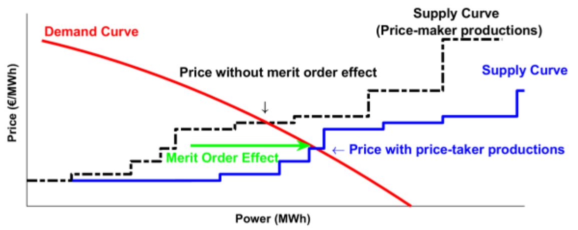

Fig. 2. The supply curve and merit order effect

curve, which is created by the bids of price-maker producers. When the price-taker producers participate in the market with close zero to MC, the supply curve shifts horizontally, as shown by the green arrow, and creates the total supply curve, shown by the blue curve. This horizontal shift, the merit order effect, leads to a new intersection between the supply curve and demand curve, as shown in Fig. 2. In other words, price-taker producers lead to a lower equilibrium price.

3.2 Forecasting Methodology

Following the day-ahead market mechanism described in subsection 3.1, this research first, identifies the average supply curve of the price-maker productions using the orthogonal regression [10], see section 5.1 for the results in the Finnish market. Estimation of the average supply curve, regardless of other features affecting the price, is not the most accurate method. However, it does not need several inputs, such as fuel price or temperature, which cannot be predicted for a long-term future.

By estimating the average supply curve of the price-maker productions, the final supply curve in the target year can be calculated by adding the effect of price-taker productions using the merit order effects. Finally, the average hourly price can be forecasted by intersecting the supply and demand curve[10], see section 5.2 for the results in the Finnish market. To divide the producers into price-maker and price-taker categories, three methods are considered:

- ***Method 1***: All productions behave as a price-maker. Therefore, no merit order effect is considered. This method can simulate the situation when all productions can control the output power, e.g. by using storage systems.
- ***Method 2***: PV and wind turbine are playing as price-taker while NPP can act as a price-maker production, e.g. by modifying their technology to provide better flexibility [11].
- ***Method 3***: PV, wind turbine and NPP play as price-taker and the rest of the production play as price-maker.

4 Finnish Electricity Market

This section analyses the historical data of Finnish electricity market. The electricity market in the Nordic region is operated by Nordpool, which is reporting the hourly day-ahead price from 2013 in [12]. The Finnish transmission system operator, Fingrid, reports also the hourly electrical

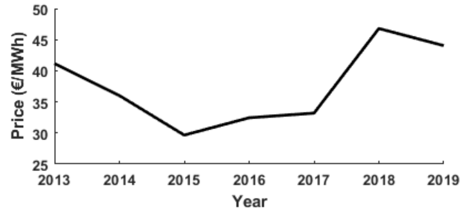

Fig. 3. The average annual day-ahead market price in Finland

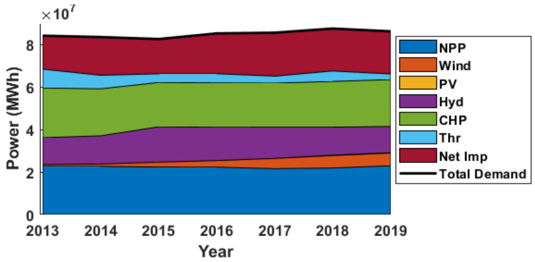

Fig. 4. The total annual production of different energy sources

consumption/production and net import power in its Open Data platform in [13].

Fig. 3 shows the average annual price of the day-ahead market in Finland from 2013 till 2019. The average electricity price has a fluctuation during the few past years. To investigate the reason for this fluctuation, Fig. 4 depicts the total annual production of different sources in Finland during the same years. Fig. 4 shows that NPP produces almost fixed energy during these years, while wind production was increased dramatically. Furthermore, PV production can be neglected and hydropower energy is reduced in 2018 and 2019, where the price peaked.

Table 1 lists the correlation coefficients between the annual average of electricity price and energy production by different sources. This correlation analysis shows that the reduction in hydropower generation could be the main factor, which leads to an increase in the average annual price of 2018 and 2019. However, the energy produced by hydropower generators depends on many factors and cannot be forecasted for a long-term.

Table 1. Correlation coefficients between annual average of electricity price and energy produced by different sources

	NPP	Wind	PV	Hyd	CHP	Thermal	Imp
Corr	0.22	0.45	0.78	-0.86	0.58	0.17	0.28

Fig. 5 shows the sensitivity analysis of day-ahead price to the production of different energy sources. As expected from the merit order effect, explained in Section 3, larger wind production leads to the lower price. However, the merit order effect for PV cannot be seen in this analysis, because of: 1) the PV production in Finland is still too little and 2) the peak of PV production coincide with demand peak on noon. Regarding NPP, the step change in the production shows that NPP work frequently with full power regardless of the market price; in other words, they are acting as price-taker sources.

Fig. 5 also demonstrates that thermal power plant will act as a price-maker, and the amount of their production will affect significantly on the electricity market. However, the thermal power plant production cannot be used as an input for long-term price estimation. The thermal productions are used mainly to compensate for the lack of production from the less costly producer, e.g. RES, NPP, or CHP.

5 Simulation Results

5.1 Supply Curves Estimation

Fig. 6 shows the power supply curves of price-maker productions in the Finnish electricity market using different methods developed in section 3. These methods find the relation between the price and the linear combination of average demand, wind, PV, and NPP productions. The other production sources are not considered directly as an input, since their value cannot be estimated independently for a long-term future. Although this simplification makes it possible to estimate the market behaviour for a long-term future, it brings some errors.

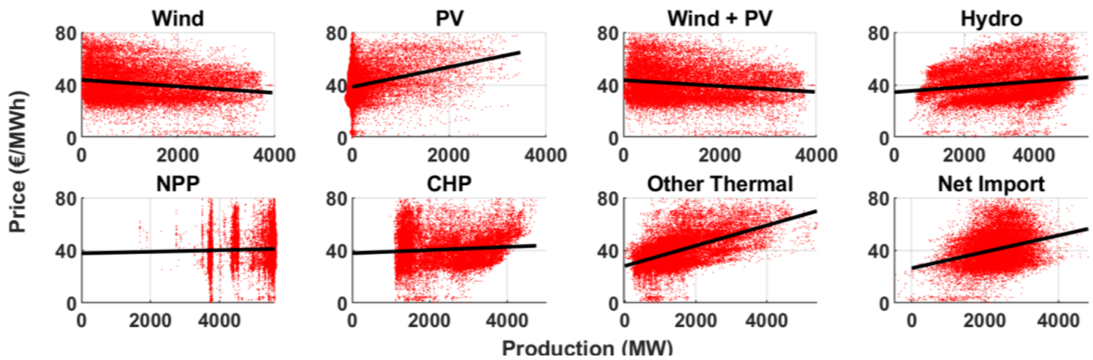

Fig. 5. The sensitivity of day-ahead price to productions of different sources, in the Finnish electricity market.

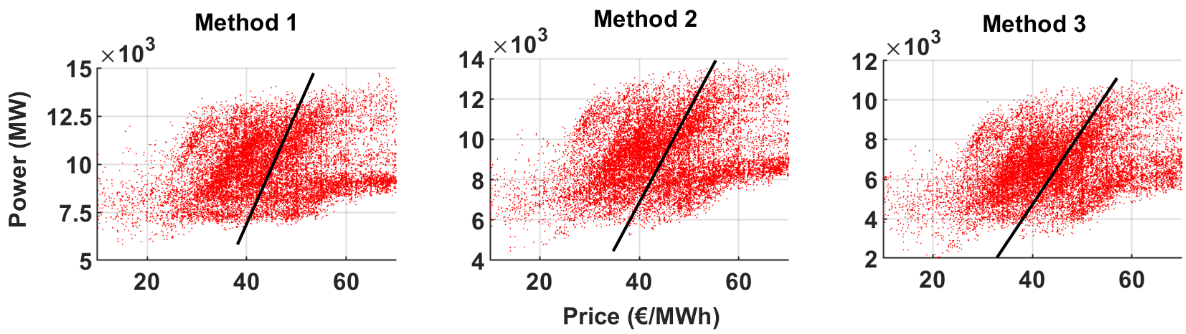

Fig. 6. The estimated supply curve, in the Finnish electricity market. Method 1: all productions behave as a price-maker, Method 2: PV and wind turbine are playing as price-taker, Method 3: PV, wind turbine and NPP play as price-taker

The red dots in Fig. 6 represent the actual value while the black lines are the estimated curve using the orthogonal regression method. These estimated supply curves represent the average value and cannot predict the price spikes caused by e.g. the extreme weather condition. In these circumstances to find out how much error comes with this simplification, Table 2 shows the mean absolute error (MAE) of method 1 to 3 when the estimated supply curves are used for the current average day-ahead price.

The result reported in table 2 state that method 3 has slightly less error compare to other methods. This result is in line with the correlation analysis as well. Table 3 lists the correlation coefficients between the hourly day-ahead price and supply curves calculated using different methods. This correlation analysis also states the slightly higher correlation between the price and the supply curve calculated using method 3.

It is noteworthy to mention that method 3 consider NPP as a price taker, which is how they were operated during these past years, as shown in Fig. 5. However, in the future by having more NPP, they may improve their technical ability and provide more flexibility in their operation, as the author discussed in [11].

5.2 Day-ahead market 2030

In order to estimate the hourly profile of the day-ahead market in 2030, the proposed methodology needs the profile of wind, PV, and NPP productions and the total demand as inputs. Here, as explained in section 1, the wind profile and PV profiles in 2030 can be estimated by multiplying the average profiles of 2018 by 2.7 and 10, respectively [1].

Regarding NPP, the Olkiluoto power plant with the capacity of 1600 MW will connect to the power system in 2022 and increase the NPP capacity of Finland from 2794 MW to 4394 MW (57% increase). Estimation of electrical demand for 2030 includes more uncertainty due to several factors, such as the electrification rate of different sectors, e.g. transportation, and replacing older consumptions with more efficient ones. Fingrid estimates demand growth between 10% (scenario #1) to 20% (scenario #2) for 2030 in comparing to 2018, which was about 87 TWh. [2]. Therefore, here, both scenarios will be simulated. The implementation of the method explained in section 3 using MATLAB Simulink accompany the data is used can be found in [14].

Table 2 The mean absolute error (%)

	Method 1	Method 2	Method 3
MAE (%)	12.36	11.70	11.18

Table 3. Correlation coefficients between horly electricity price and different methods

	Method 1	Method 2	Method 3
Corr	0.34	0.35	0.38

Fig. 7 shows the estimation of day-ahead price in 2030 using different methods. Method 1 neglects the uncontrollable nature of the upcoming wind and PV productions. Therefore, it represents the scenario when NPP has a more flexible operation and wind and PV productions can act as a price maker, e.g. by having some storage system. In this case, the average day-ahead price could reach 49 €/MWh, which is almost in the same range of recent years, as shown in Fig. 3.

However, if NPP, wind, and PV productions continue to behave as a price-taker, method 3, the average day-ahead price could be as low as 41 €/MWh. Comparing method 2 and method 3 shows that the operation of NPP could have a larger effect on the day-ahead market than wind and PV. Method 2 considers that NPP has enough flexibility to operate as price maker and the merit order effect is applied just for wind and PV. In these circumstances, the average price will be between 45, Scenario #1, to 47, Scenario #2, €/MWh.

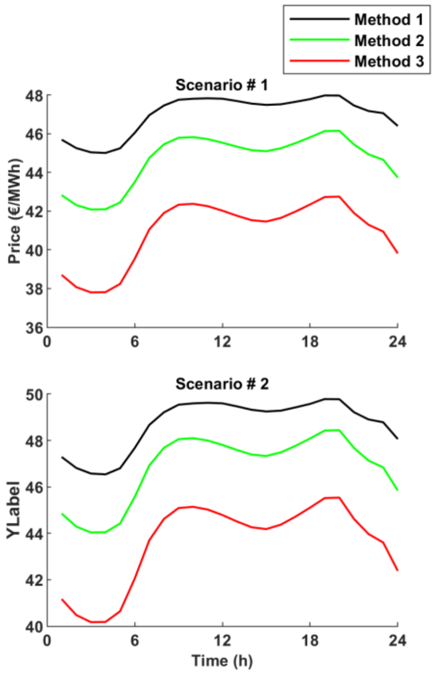

Fig. 7. The estimation of day-ahead price in 2030,

6 Conclusion

This paper analyses the Finnish electricity market and presents a methodology to forecast the price profile of the long-term day-ahead electricity market. The proposed methodology can also be applied to other countries to get a good estimation of their electricity price in the future. Since it is not possible to estimate several inputs, such as weather conditions, with acceptable error for a long-term future, the methodology developed here does not need many detailed inputs. The required input can be estimated using the high-level energy plan of the country/region, such as the target level of PV or Wind.

This paper estimates the average price profile of day-ahead market in 2030, using three different assumptions. If the wind turbine, PV, and NPP act as price-taker as behaving now, the average electricity price will reduce significantly, method 3 represents this assumption. However, if all productions can control their output, e.g. by having storage system, they will act as price-maker and can control the market price, method 1 represents this assumption. Besides, the simulation shows that the new NPP, Olkiluoto, has a significant role in the market and if they want to continue mostly as price-taker, they will reduce the market price significantly, even more than wind and PV, comparison of method 2 and method 3.

7 Acknowledgements

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