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Economic impact of renewable electricity generation on the Baltic region's electricity market

***Abstract**. This paper analyses the increasing wind integration impacts on the Baltic region's electricity market participants and power plant economics in the year 2025. Continuing subsidising impacts with currently implemented supporting mechanism is discussed. The last section addresses the key findings that large-scale wind integration, deployed under full market conditions, might have on the economics of different generation technologies, with and without subsidies.*

Streszczenie.** Niniejszy artykuł analizuje rosnący wpływ elektrowni wiatrowych na uczestników rynku energii elektrycznej i ekonomię elektrowni w regionie Bałtyku do 2025 roku. W artykule omawiany jest również wpływ kontynuacji dofinansowania wg. przyjętego obecnie mechanizmu wspierającego. W końcowej części omówiono najważniejsze ustalenia, dotyczące potencjalnego wpływu wielkoskalowej energetyki wiatrowej, wdrożonej w warunkach wolnorynkowych, na ekonomikę zastosowania różnych technologii generacyjnych, zarówno z subsydiami jak i bez subsydiów. (**Wpływ ekonomiczny odnawialnych źródeł energii elektrycznej w bałtyckim regionie rynku energii elektrycznej)

Keywords: electricity market, large-scale wind integration, power system economics.
Słowa kluczowe: rynek energii elektrycznej, energetyka wiatrowa dużej skali, ekonomia systemu elektroenergetycznego.

Introduction

According to the International Energy Agency's (IEA) 2010 World Energy Outlook report [1] the European Union (EU) has taken a political decision to restructure the power industry to a less carbon-intensive one. Contrary to the world's trend, the EU is planning to decrease the share of coal produced electricity and the majority of new generating capacity additions derive from renewable technology, e.g. EU is planning to invest by 2035 in new power plants over 2.4 trillion (10^{12}) euros, from which more than 70% is destined for renewable technology.

The EU's policy affects mainly those countries whose energy portfolios are mostly based on large thermal power plants utilizing fossil fuels, e.g. the Baltic States. Replacing all the old thermal power plants in Estonia, Latvia and Lithuania with new capacities that would cover the peak demand and at the same time fulfil the EU's objectives, seems at least in the following decades more than impossible without additional supporting mechanisms.

This paper covers the methods and results of the analysis carried out to determine the impacts that large-scale wind integration has on the Baltic region's electricity market and power generation in 2025. The model has been updated to additionally analyse how the supporting mechanisms for renewables (implemented in 2010) might distort the market in 2025.

The Estonian transmission system operator (TSO) has adopted a market modelling software for analysing power flows and market prices in the future to determine the necessary grid development projects and analyse the market performance. However, there have not been made any analysis on how increasing wind capacities and renewable supporting mechanisms actually influence the whole Baltic region power plant economic viabilities together. The model and methods described in this paper are currently one of its kind, that cover all the region's power plants and their economic aspects as close to reality as possible.

The paper has been divided into five sections. Where the second section covers an overview of the previous papers published on large scale wind integration impacts on deregulated markets. The third section covers the model and the methods used. The fourth describes the modelling results and impacts of large scale wind integration and the final section summarizes the key findings.

Previous papers on large-scale wind integration impacts

In [5] Olsina *et al.* developed a methodology for evaluating the optimal wind capacity that could be profitable integrated into system with liberalised electricity market. The work focused on the perspectives of a wind power plant operator. The simulations showed that large-scale wind integration might significantly reduce the electricity price on the market, which in the short-term might be positive for the society but in the long term it jeopardizes the economic viability of conventional generators. The main conclusion stated that large-scale wind capacity deployment on a deregulated market is possible only in case of high fossil fuel prices or with some additional financial incentives (lower investment costs or subsidies).

Lamont described with his work [6] that introducing intermittent generation (in his case solar and/or wind) tended to decrease the overall marginal costs of the system. In the short term this was achieved through avoiding fuel and variable costs of conventional (dispatchable) generation, which was achieved through reduced utilization hours. In the long term it makes the conventional technologies unreasonable and thus reduces the security of supply, but at the same time it gives an incentive for restructuring the generation portfolio to meet the new power system configuration requirements with less base capacities.

Increased wind integration thus restructures the power system's capacity allocation. However, it is doubtful that it will fully replace conventional units that are able to cover peak loads. This is affirmed by Boyle in [3], that the total dispatchable capacity in a system will never be less than the peak load irrespective the amount of integrated intermittent generation.

MacCormack *et al.* in [7] examined the effects of large scale integration of wind powered electricity generation in a deregulated energy-only market on electricity prices, reliability of supply and dispatchable suppliers' economics. The analysis results showed also that in medium term, large integration level of wind power can lead to reduced market prices and increased reliability of supply due to the dispersion of wind power plants in the power system. However, increased wind integration also decreases the utilization hours of conventional power plants, thus increasing their average costs. In the long term revenues collected from the market should be at least equal to the average cost of production, or sufficient dispatchable capacities will not be built and the security of supply will deteriorate. However, the author also suggests that this deterioration might give the incentives to restructure the generation mix.

Baltic region's electricity market model

The market model described here was originally developed in [4], and was used to give a rough analysis of the impacts that increasing wind capacity in the power system has on the dispatchable units' economics under different market conditions. However, the model has been modified to carry out more comprehensive analysis on how current subsidising methods and increasing wind capacities might affect the market and other market players.

Several simplifications and assumptions were used, but all the input data used in the model is based on facts or best available data from the literature. The model assumes that the electricity market operates under perfect competition and all three countries of the Baltic States are trading in one price area, hence the name Baltic region electricity market. Although the Baltic region electricity market is part of the Nordic Countries electricity market (Nord Pool Spot) the current model disregards this and assumes the Baltic States are operating separately in an so called "island mode" and have no actual power exchange with any of their neighbouring power systems.

Availability and utilization factors of different power plant units are based on either literature or statistical data. The hourly capacity factors of onshore wind turbines, offshore wind turbines and large hydro power plants are based on statistical data provided by each country's TSO for the wind study [8], which analysed the possibilities and limitations for integrating wind capacities in the Baltic power system. The availability and sudden failures of other generating technologies is taken into account by the availability factor from the literature [9].

The demand model is based on the regions 2010 hourly consumption values, provided by the Estonian TSO. 2010 was chosen as a reference point because it is the newest and most accurate data available for the Baltic power system. 2025 consumption data was achieved by applying forecasted growth per cents [10] for each hour of the year. The model can be summarized as follows:

- type – electricity pool;
- modelled year – 2025;
- fuel prices – according the Estonian TSOs Balmorel market model results for the year 2025 based on the IEA's reference data, see Table 1;
- externalities:
  - implemented CO_2 tax is 25 €/t, based on ENTSO-E[1] market database information;
  - implemented subsidies are elaborated in more detail later in this paper.

Table 1. 2025 Projected prices of the fuels used in the model [2]

Fuel	Coal	HFO	Oil shale	NG	Woodchips
Price, €/GJ	2.93	12.64	2.51	8.52	6.95
Price, €/MWh$_{fuel}$	10.53	45.51	9.02	30.66	25.02

The modelling methodology is based on the electricity pool principle described in different power system economics handbooks [11, 12]. All the producers bid on the market according to their short-run marginal costs (SRMC). After all the bids have been submitted and the gate for the trading hour has been closed the bids are arranged from the smallest to the highest. This list of arranged bids gives the merit order curve of dispatching units at the trading hour. The system's marginal price (SMP) or electricity price at a specific trading hour is determined by the last unit that covers the demand forecast, see Fig. 1.

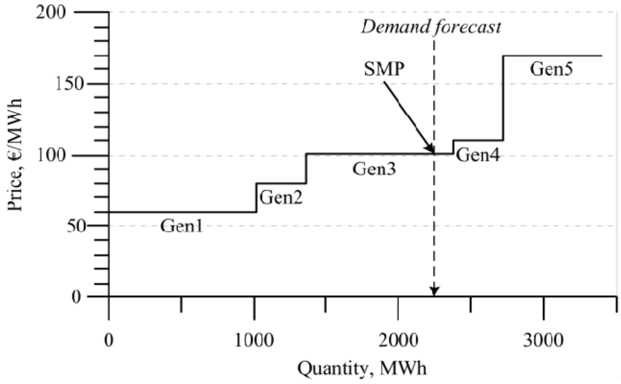

Fig.1. The used modelling principle of electricity pool [11]

Based on the theory provided by the literature [11, 12] the authors have formulated the SRMC as follows:

$$SRMC = \frac{C_{fuel} + C_{ext}}{\eta_{PP}} + C_{var} \quad (1)$$

where: $SRMC$ – short run marginal cost of the unit, C_{fuel} – forecasted price of the fuel used, η_{PP} – power plant's efficiency, C_{var} – variable cost of production, C_{ext} – external cost of production (environmental taxes).

Market data obtained from the model is then used to evaluate different technologies' economics, which is based on comparing the long-run marginal cost (LRMC) of the power plant with the revenues collected from the market. Equation (2) is used to evaluate the economic viability of technologies.

$$\frac{\sum_{i=1}^{8760} MR_i}{\sum_{l=1}^{8760} EP_l} > LRMC \Rightarrow \begin{cases} FALSE, \text{economically not viable} \\ TRUE, \text{economically viable} \end{cases} \quad (2)$$

where: $LRMC$ – long-run marginal cost of the unit, MR_i – hourly revenue collected from the market, EP_l – energy supplied hourly to the market.

LRMC takes into account in addition to the SRMC also the capital (operation and maintenance) and investment costs. The following formulation of the LRMC was used in the model:

$$LRMC = SRMC + \frac{C_{investment}}{EP_a} + \frac{C_{fix}}{EP_a} \quad (3)$$

where: $LRMC$ – long-run marginal cost, $SRMC$ – short-run marginal cost, $C_{investment}$ – discounted (8%) annual investment cost during the unit's technical life time, C_{fix} – annual fixed costs occurring irrespective of the unit's utilization time, EP_a – total energy produced in one year.

All the necessary technology specific data for calculating the above mentioned costs are based on either literature, see references [9], [13] and [14], or in case of oil shale technology data available and provided by the Estonian TSO. The following two market scenarios, each with two different wind integrations levels, have been used:

[1] ENTSO-E – European Network of Transmission System Operators for Electricity

- 2025 market with currently implemented supporting mechanisms;
- 2025 market without supporting mechanisms.

The wind integration levels were chosen taking into account the maximum possible technical capacities according to [8]. The following wind integration levels for each country were thus used:

- low wind integration level 250 MW offshore capacities and 250 MW onshore capacities – total installed wind capacity in the Baltic States power system 1500 MW;
- high wind integration level 450 MW offshore capacities and 450 MW onshore capacities – total installed wind capacity installed 2700 MW, which represents the maximum possible integration of wind power into the Baltic electricity system without wind generation down curtailment [8].

Supporting mechanisms data used in the model for Estonian wind and CHP technology is based on the current legislation in Estonia [15] and for the rest of the technologies it is based on statistics of actually paid subsidies provided by the TSOs [16]. The premium values used in the model are summarized in Table 2.

Table 2. Implemented subsidies used in the model

	Estonia, €/MWh	Latvia, €/MWh	Lithuania, €/MWh
Wind power	53.70	67.75	SRMC
CHP	32.00	N/A	SRMC
Biomass CHP	50.67	67.75	SRMC
Biogas	N/A	79.88	N/A

The premiums are only taken into account in the calculation of the bidding price with what the power plant bids on the market, increasing its chances to produce electricity on the market. Equation (4) describes the calculation methodology of the bidding price:

$$BP = SRMC - S \tag{4}$$

where: *BP* – bidding price with what the power plant bids its capacity on the market, *SRMC* – power plant's short-run marginal cost, *S* – subsidy what the state has guaranteed for the renewable electricity producers or CHP plants.

The generation portfolios (except wind power) for each country in 2025 were created according to the TSOs national development plans described in [2], [8], and [17].

Modelling results

The impacts that increasing wind penetration into the power system has on the average market prices, with and without subsidies, are summarized in Table 3.

Table 3. Summary of the wind integration impacts on market price

Wind integration level	Market price without subsidies, €/MWh	Market price with subsidies, €/MWh
1500 MW	76.08	73.31
2700 MW	68.05	64.57

The increasing capacity of wind power in the system inevitably decreases the electricity prices on the market because it alters the merit order curve of dispatching. In this case the distortion of the merit order curve takes place due to the increased capacity provided by wind power. The last unit that determines the SMP might be shifted in the merit order curve and thus also the price lowered at some trading hours which decrease the overall average price on the market. Impacts on utilization factors by technologies used in the power system have been summarized in Table 4.

Table 4. Summary of the wind integration impacts on utilization factors, utilization factor of 1 corresponds to 8760 working hours

Technology	Wind integration level	Without subsidies	With subsidies
Oil shale CFB[a]	1500 MW	0.970	0.954
	2700 MW	0.892	0.868
Coal CFB	1500 MW	0.986	0.942
	2700 MW	0.923	0.812
CCGT[b]	1500 MW	0.749	0.689
	2700 MW	0.587	0.527
Biomass	1500 MW	0.851	1.000
	2700 MW	0.690	1.000
Biogas	1500 MW	0.310	1.000
	2700 MW	0.192	0.999

[a]CFB – circulating fluidized bed combustion technology
[b]CCGT – combined-cycle gas turbine technology

It can be derived from the analysis that in case subsidies are applied large scale wind integration has the biggest impact on those base load technologies that utilize more expensive fuels (i.e. coal and natural gas). If no subsidies have been applied the situation changes, as also biogas and biomass technologies will be affected by the shifts in the merit order curve of dispatching described in the previously. Utilization hours might be reduced up to 38%, depending on the type of the technology.

The economic viability of the technology can be evaluated by the gap between the LRMC and the average price received from the market. The market situation with implemented subsidies is represented in Fig. 2.

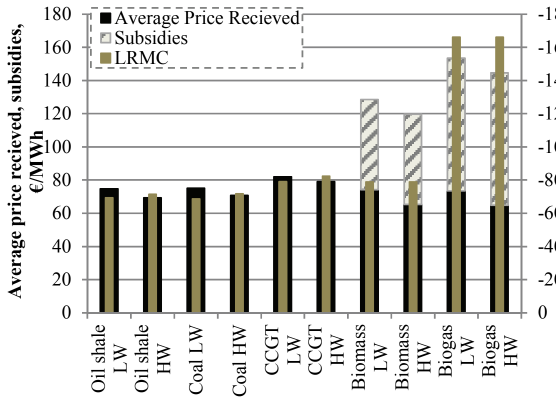

Fig.2. Economics of different technologies with implemented subsidies; LW – low wind integration; HW – high wind integration

The results show that oil shale, coal and CCGT technologies in the long run might become economically not feasible if the wind integration level increases to 2700 MW. Biomass technologies are almost not affected by the increase of wind capacities in the system; this is ensured by the subsidies that they receive. However, it can be seen that the level of subsidies is abnormally high compared to the costs occurring and thus giving significant leverage for this technology over others. On the other hand biogas technology's occurring costs are still higher even with additional subsidies and with the increase of wind integration level the gap between costs and revenues increases.

The market situation without subsidies is somewhat similar, but due to the higher market prices most of the technologies will not lose their economic viability in case the wind penetration level in the system increases. In addition it brings out the real competitiveness of different technologies on the open electricity market. Fig. 3 represents the modelling results of the market without subsidies.

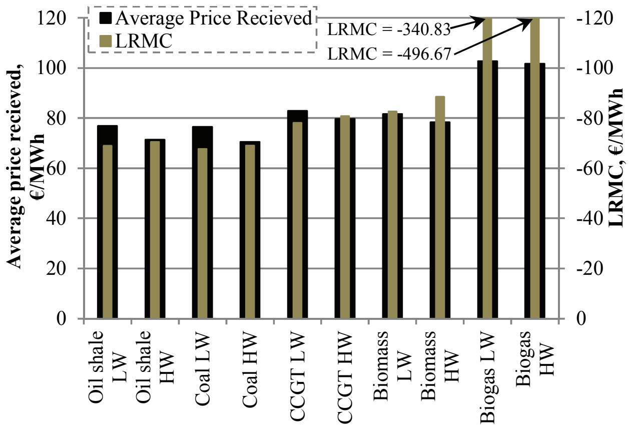

Fig.3. Economics of different technologies without implemented subsidies in case of different wind integration levels

Although there is still one externality (CO_2) implemented it can be seen that the used fuel plays a key role in being economically feasible on the market. Nevertheless, most of thermal power plant technologies are quite competitive and relatively feasible on the open market even without subsidies. In case the wind integration level increases, it mainly affects biomass and –gas technologies. Here it can be seen that biogas technology is relatively expensive and for it to become feasible it requires higher utilization factors and even financial support.

Although wind power is the key factor that affects the market and other market players, the model also showed that increasing wind integration affects also its own economics. Fig. 4 describes the economics of onshore wind technology and Fig. 5 represents the modelling results for onshore wind capacities with subsidies.

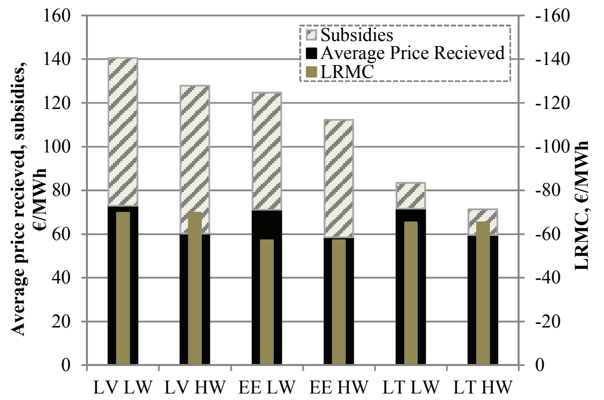

Fig.4. Economics of onshore wind technology in LV – Latvia, EE – Estonia, LT – Lithuania with implemented subsidies in case of different wind integration levels

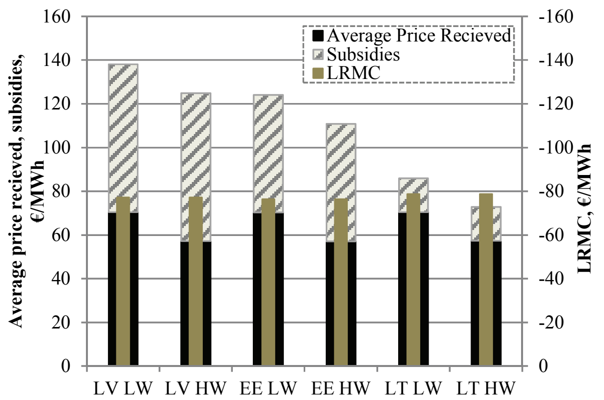

Fig.5. Economics of offshore wind technology with subsidies

As it turns out, deploying wind capacities under full market conditions significantly increases their revenues compared to the regulated market where they would have to settle with a fixed price. Thus keeping the subsidies levels as high as they were on the regulated market is unreasonable. From one hand it is an extra cost for the society and on the other hand it distorts the market by significantly favouring a certain technology. In the long term this jeopardizes investments into other technologies as they would be less profitable on the market compared to subsidised technologies. This in return might lower the security of supply in case of capacity deficit.

The model without implemented subsidies showed somewhat similar results than the model with subsidies. There were marginal differences between the average prices received from the market, but the overall situation stayed the same implying that subsidies have the least influence on the economics of wind power. Olsina et al. in [5] described, that there is a maximum level of wind power capacity that could be profitably deployed under full market conditions. Here the results indicate that if the wind integration level increases the onshore technology might lose its feasibility, implying that the Olsina's suggested maximum level of economically dispatchable wind power has been exceeded. However, the economic threshold up to what it is feasible to deploy either technology also varies by country (different wind resources). So theoretically it should be possible to reach a mix of technologies in the wind generation portfolio that would be economically feasible in both market situations.

Conclusion

In this work, the impacts of large-scale wind integration on the local electricity market and power generation in 2025 has been analysed. The developed fictive market model allowed investigating the impacts of renewable supporting mechanisms and increasing wind capacity effects on the market situation and economics of different generation technologies. The carried out analysis is one of its kind that covers all the Baltic region's power plants and their economic aspects as close to reality as possible. The modelling results provide information i.e. about the changes of the utilization hours, shifts in the merit order curve of dispatch, changes in revenues collected from the market.

One part of the modelling results have reached same results as previous studies before, showing that increasing capacity of wind power in the system decreases the electricity prices on the market by altering the merit order curve of dispatching. The analysis covering impacts on utilization hours indicated that even if externalities (CO_2 taxes and subsidies) have been implemented, the increase of wind integration levels in the power system has the biggest impact on those technologies that utilize more expensive fuels. The analysis covering subsidies indicated that liberalizing the market enables all the producers to sell their product on equal basis. Eliminating the subsidies brought out the real competitiveness of different technologies and showed that most of the technologies might actually not require additional financial support.

Although wind power played the key factor in affecting the market and other market players the model also brought out the shortcomings of increasing wind penetration on its own economics. The model indicated that onshore technology, once deployed under full market conditions, is economically feasible even without subsidies. At the same time offshore technology, while still under development for large scale deployment, might require additional financial support in certain situations. However, if the wind integration level increases the onshore technology might lose its feasibility, meaning it is extremely important to analyse the mix of wind technologies deployed on the market, to ensure its feasibility. Theoretically an optimal mix of off- and onshore technology can be reached that ensures the feasibility of both.

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