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WIND FARM ENERGY PRODUCTION IN BOSNIA AND HERZEGOVINA: LEVELIZED COST OF ENERGY

Rejhana Blažević, Halima Hadžiahmetović, Džana Kadrić & Mirela Alispahić

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Abstract

This paper analyses the levelized cost of energy (LCOE) for wind farms currently operating in Bosnia and Herzegovina (B&H). An overview of existing wind farms and planned projects in B&H is provided. The methodology for calculating LCOE is presented, where LCOE represents the electricity selling price needed for wind farm investors to recover capital costs. Using this methodology, LCOE values were calculated for three operational wind farms in B&H - Mesihovina, Jelovača, and Podveležje. A sensitivity analysis was also conducted by varying key parameters like discount rate, plant lifetime, operation and maintenance costs (O&M), and energy output. The results showed LCOE is most sensitive to discount rate variations, while changes in operations and maintenance costs have the least impact. This analysis provides valuable economic assessment of wind power investments in B&H. The calculated LCOE values can inform policy-making and incentives aimed at further growth of cost-competitive wind energy to support B&H's renewable energy and decarbonization goals aligned with the European Union (EU).

Keywords: renewable energy sources; wind farm; levelized cost of energy (LCOE); decarbonization; electricity production; wind atlas;

1. Introduction

The energy sector is responsible for over 70% of global CO_2 emissions, representing the greatest potential for reducing greenhouse gases [1]. The power sector, as the single largest source of CO_2, must undergo significant transition to reduce emissions. Currently, Bosnia and Herzegovina (B&H) energy production relies heavily on coal (≈66%) and hydropower (≈33%). The share of wind farms and solar photovoltaic power plants is less than 3% [2]. To align with the EU, B&H must increase system energy efficiency, energy security, transition from coal, and accelerate transition to renewable energy sources. The EU aims to reduce greenhouse gases for 80-95% below 1990 levels by 2050, requiring complete decarbonization. The strategy for achieving these goals is clear, namely the transition to sustainable, renewable energy sources and a significant improvement in energy efficiency [3]. B&H path to decarbonization have made significant strides, particularly with the signing of the Sofia Declaration on the Green Agenda for the Western Balkans in November 2020. This commitment aligns the country with the EU goals for energy transition and carbon neutrality by 2050, as well as establishing an energy transition plan until 2030 [2], [3], [4]. To achieve the necessary reduction in greenhouse gas emissions by 2030, B&H will primarily need to shut down outdated and inefficient thermal power plants and replace them with renewable energy sources. Additionally, the country will need to introduce an emissions trading system and implement numerous energy efficiency measures to reduce energy consumption.

Bosnia and Herzegovina strategic commitment to include renewable energy sources in the energy production system, particularly wind farms and solar power plants, is evident in various studies analysing the country wind potential and the development of wind farms. The country has set ambitious targets for increasing energy efficiency and the use of renewable energy sources, with a goal of achieving a 43.6% share of renewables in gross final consumption by 2030. The forthcoming National Climate and Energy Plan will help Bosnia and Herzegovina to ensure energy security while improving its long-term resilience to climate change.

Numerous studies have analysed the wind energy potential in various countries and the particularities of legislation, challenges, and perspectives for wind farm development [5]. Several studies presented assessment of wind potential at specific locations in B&H. For instance, the wider area of Sarajevo area was examined, concluding insufficient wind potential for wind-powered electricity generation in Sarajevo, while the available wind energy potential near Sarajevo on Bjelašnica mountain is very high [6], [7]. When evaluating wind farm profitability, the electricity production cost for a given site is analysed. Tizgui et al. assessed wind potential and compared electricity production costs from nine wind farms in Morocco, finding lower production costs than the guaranteed electricity purchase price [8]. Similarly, Bahrami et al. utilized performance indicators to evaluate technical and economic feasibility of systems in Uzbekistan, determining the critical specific investment cost to equalize energy production cost and the electricity tariff [9].

Onshore wind farms account for 90% of the total wind energy capacity in EU, and most of the new wind energy capacity under construction is also onshore. In B&H, new onshore wind farms are being constructed to expand renewable energy capacity. Across EU, onshore wind energy represents the most cost-competitive form of new electricity generation, as demonstrated by levelized cost of energy (LCOE) analyses. Figure 1 illustrates the wide range of LCOE for different technologies in Germany in 2021. Onshore wind is on the lower end of the cost spectrum, demonstrating its competitiveness [10].

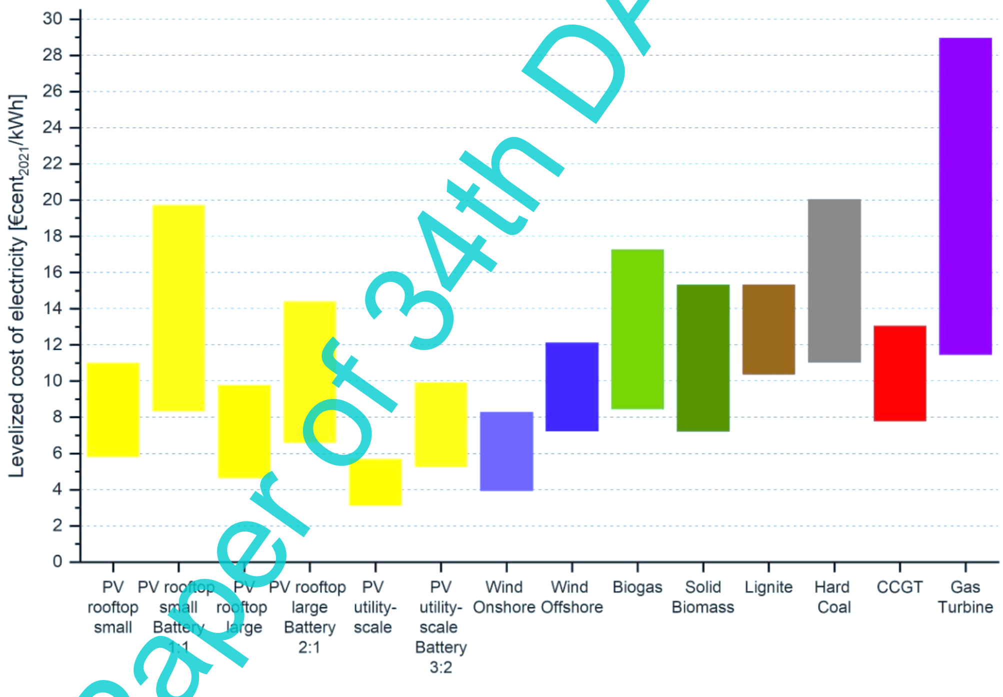

Fig. 1. Levelized cost of energy of renewable energy technologies and conventional power plants in Germany in 2021 [10]

All renewable energy technologies continue to record decreasing LCOE. From Figure 1 it can be seen that the LCOE of onshore wind power plants in 2021, with specific plant costs ranging from 1.400 to 2.000 €/kW, were between 3,94 and 8,29 €cent/kWh, or 39,4 and 82,9 €/MWh [10].

The main goal of this research is to calculate and present the levelized cost of electricity (LCOE) values for three wind farms in B&H that are currently in operation. The obtained LCOE results are analysed and compared. An appropriate LCOE calculation methodology was developed and is presented in this paper. As part of the analysis, the sensitivity of the LCOE to variations in key parameters like the discount rate, plant lifetime, operation and maintenance costs, and energy output variability was also investigated.

2. Wind potential in Bosnia and Herzegovina, an overview of existing systems

In the electricity development strategy of B&H until 2030, wind energy occupies a significant place. Wind energy has significant potential in B&H, especially in the southern and western regions. Measurements conducted at around 30 potential wind farm locations found average annual wind velocities of 6-8 m/s at a height of 50 meters. The total potential of the observed locations, from the point of view of the available space, is estimated at about 900 MW, Figure 2. If the availability of suitable spaces (connection to the network, environmental protection, etc.) is not taken into account, the total technical wind potential is significantly higher and is estimated at about 2000 MW [11]. However, a detailed wind atlas mapping wind velocities and power densities at different heights is lacking, which creates uncertainty in potential assessments. The selection of the optimal location for constructing a wind power plant depends on technical, economic, and environmental constraints. The initial technical analysis involves assessing the wind potential at a given site. By conducting long-term wind measurements and using topographical maps of the terrain, wind potential maps can be created, including maps of mean annual wind velocity (m/s) and mean annual wind power density (W/m^2) at different heights.

A major challenge for B&H is the lack of a wind atlas, which serves as the foundation for detailed research and, together with other spatial data like topographic maps and satellite images, enables credible evaluation of the country wind energy potential. Precise determination of wind potential necessitates the most accurate indicators, i.e. a detailed wind atlas, which requires continuous multi-year measurements per standards and regulations. Creating a wind atlas involves long-term assessment of the wind regime and terrain through field measurements and numerical modelling [12]. Wind atlases provide wind velocity and direction data in the form of maps, time series, and distributions at different heights. They are used to pre-select wind farm sites by providing high-resolution data on wind resources. The Global Wind Atlas offers freely accessible global wind resource data to facilitate site selection and planning. Overall, a detailed wind atlas formed by sustained standardized measurements over several years is essential for accurately evaluating wind potential and siting wind power plants.

Since wind atlas data and wind maps are not available for B&H, the assessment of wind energy potential in the country is primarily based on the spatial distribution of average annual wind velocity and power. These data are the result of applying the global atmospheric model formulated in the World Wind Atlas [11], [13]. The World Wind Atlas utilizes global meteorological information, and the results obtained from this model have not been verified with ground measurements. While on-site measurements would provide more accurate results, this wind atlas can be considered sufficiently representative for an initial, indicative evaluation of wind potential in B&H [13].

Figure 3, taken from [13], shows the general spatial distribution of average annual wind velocity across B&H. It indicates that the highest wind potential is in the southwestern part of the country. According to world wind atlas, almost 50% of the land area of B&H has an average wind velocity above 6 m/s. Figure 4 depicts the surface roughness length in B&H, while Figure 5 shows the orography. Surface roughness greatly impacts wind velocity – as roughness increases, so does drag, slowing down the wind. With increasing height above ground level, the influence of roughness decreases and wind velocity increases. Figure 4 shows that roughness in southwestern Bosnia and Herzegovina ranges from 0,03 to 0,1, corresponding to roughness classes 1 and 2 per the European Wind Atlas. Figure 5 indicates that B&H has complex terrain. Elevation in the southwest, where wind potential is highest, varies from 300 to 1700 meters above sea level.

Fig. 2. The area with the highest wind potential [11]

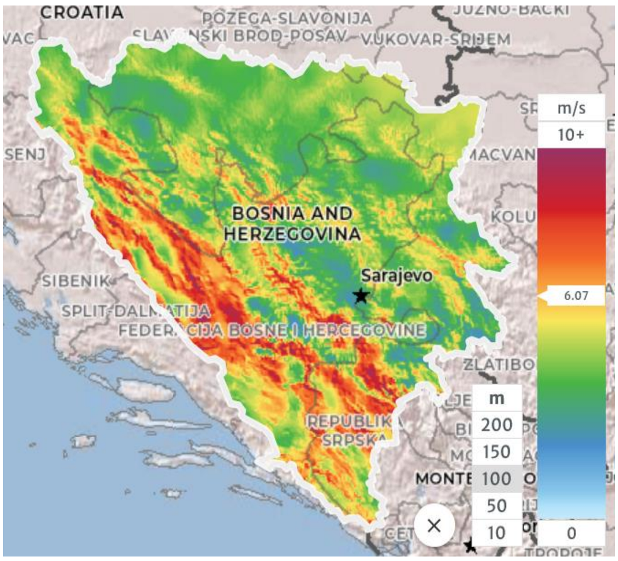

Fig. 3. Wind potential in Bosnia and Herzegovina [13]

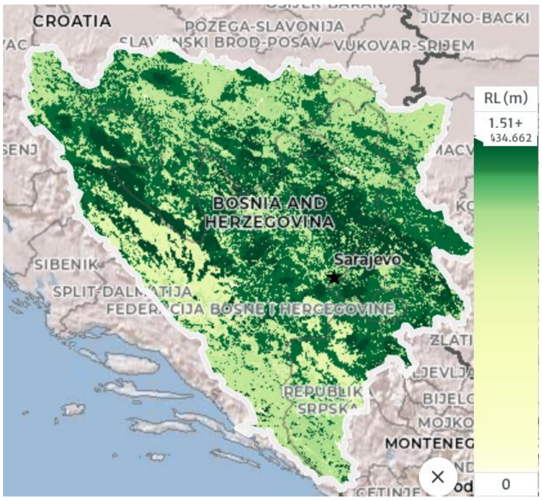

Fig. 4. Roughness length in Bosnia and Herzegovina [13]

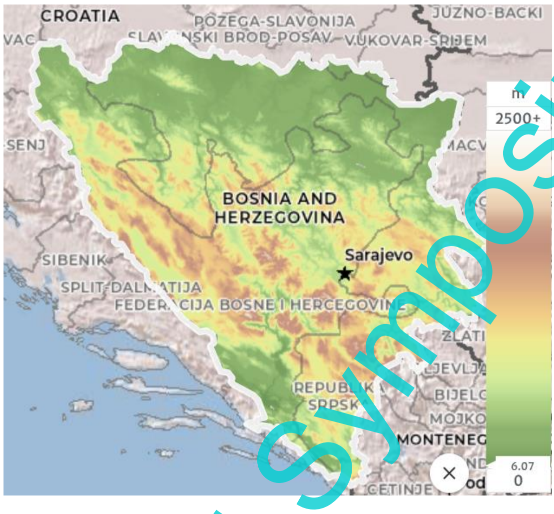

Fig. 5. Orography in Bosnia and Herzegovina [13]

Bosnia and Herzegovina has recently begun constructing wind farms at several locations, with some already completed and operational. The country currently has three wind farms producing electricity, representing a total investment of around €200 million. Two wind farms are located in the Tomislavgrad area (the Mesihovina wind farm operational since 2018 and the Jelovača wind farm since 2019), while a third in the Podveležje plateau above Mostar started producing electricity in early 2021. Two wind farms are owned by the state and one is privately owned. Funding was provided primarily through loans from the German Development Bank. Together, these three wind farms generate approximately 400 GWh of electricity per year on average.

The Mesihovina wind farm, located near Tomislavgrad, has a total of 22 wind turbines of type SWT-2.3-108 manufactured by Siemens Gamesa, with a total installed capacity of 50,6 MW. The Jelovača wind farm, also located near Tomislavgrad, consists of 18 wind turbines from Siemens Gamesa's 2.0 series, with a total installed capacity of 36 MW. The Podveležje wind power plant near Mostar has 15 wind turbines and a total installed capacity of 48 MW. Considering technological advancements and global trends in wind power utilization, it is realistic to expect increased construction of wind farms and their integration into B&H energy system. The extent of wind power development in B&H will largely depend on the policies and actions of state and entity administrations regarding wind energy utilization. Table 1 provides an overview of existing wind farms in Bosnia and Herzegovina [2].

Wind farm	**Electric Utility of B&H**	**Total Power**	**Power of aggregate**	**Location of wind farm**	**Annual production of electricity**	**Commissioning**
-		MW	MW	-	GWh	-
Mesihovina	PE " Electric Utility HZ HB"	50,6	22 x 2,3	Municipality Tomislavgrad	165	2018
Jelovača	FL WIND d.o.o.	36	18 x 2	Municipality Tomislavgrad	110	2019
Podveležje	PE " Electric Utility B&H"	48	15 x 3,2	Mostar city	130	2021

Table 1. Wind farms in Bosnia and Herzegovina [2]

Public Enterprise Electric Utility of B&H is working on the Bitovnja wind power project near Konjic, which plans to install 25 wind turbines with a total capacity up to 60 MW and estimated annual production of 110 GWh. Additionally, there are plans for the 50 MW Vlašić wind power project with 18 turbines and expected annual production of 115 GWh. The 2019-2029 Development Plan of Public Enterprise Electric Utility of Republic Srpska defines activities for implementing renewable energy projects including three wind farms - Hrgud, Donja Trusina, and Radimlja.

New laws were passed in the Republic Srpska entity in 2022 and the Federation entity in 2023 to promote renewable energy growth through measures like auctions for feed-in tariffs, renewable energy communities, and simplifying administrative procedures, therefore it is expected that number of wind farms will grow in the future.

3. Methodology for estimating levelized cost of energy production from wind farms

Levelized cost of energy (LCOE) is a widely utilized economic assessment metric used to calculate the average cost per unit of electricity generation (kWh) expressed in net present value (NPV) throughout the lifetime of the plant. In other words, LCOE is an economic estimate of the total cost of construction and operation of an electricity production plant during its lifetime divided by the total amount of electricity produced [14]. It represents the break-even price for an asset over its lifetime and is widely used for investment decision-making and policy analysis in the energy sector. The LCOE enables consistent comparison of different electricity generation technologies across key economic and technical parameters such as capital costs, capacity factors, fuel costs, operating life, and financing costs. However, the LCOE methodology has limitations, as it does not fully capture integration costs, risk, and other externalities. The LCOE calculation methodology and key assumptions can significantly impact results, so transparency is critical. Various methodologies for calculating LCOE can be found in different literatures [15].

LCOE can be expressed as [15], [16]:

$$LCOE = \frac{C_{annual,total}}{E_{system,output}} \quad (1)$$

where $C_{annual,total}$ is total annual investment costs of the system and $E_{system,output}$ is total annual output power produced by the wind farm during lifetime.

The annual energy produced by the system can be estimated by following expression:

$$E_{system,output} = 8760 \cdot P_{inst} \cdot CF \quad (2)$$

where P_{inst} is total plant capacity in kW and CF is capacity factor.

The LCOE method is based on the net present value (NPV), i.e. every future cost must be adjusted to the present value due to inflation and other factors. Therefore, the basic expression for LCOE is [17], [18], [19]:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (3)$$

where $LCOE$ is levelized cost of energy which is expressed in monetary units per kWh or MWh, I_t is investment costs in the year t in euros, M_t is operation and maintenance cost in the year t in euros, F_t is fuel cost in the year t in euros, E_t is electricity generation in the year t in MWh, r is discount rate in percentage, n is lifetime of the system (project evaluation period) in years and t is year of lifetime (1, 2, ..., n).

Investment costs are the main expenditures in the process of constructing a power plant in relation to the installed power of the plant. They relate to the planning, design and construction of the plant, and vary depending on the type of plant. Power plant construction costs are usually expressed as a specific investment per unit of installed power according to the expression:

$$I = I_{spec} \cdot P_{inst} \quad (4)$$

where I_{spec} is specific value of the investment in €/kW P_{inst} is total plant capacity in kW.

The total investment value for the three analysed wind farms is known, so this value was utilized in the levelized cost of energy (LCOE) calculation.

Fuel costs do not exist for plants producing energy from renewable sources. Instead, there are only operating and maintenance costs as periodic expenses. Although cost analysis can be very detailed, this paper simplifies it as a sum of fixed and variable costs regardless of energy produced. These costs are already expressed relative to plant power, following the methodology of the Rulebook on determining guaranteed electricity purchase prices from renewable energy and efficient cogeneration facilities. This was adopted by the Regulatory Commission for Energy in the Federation of Bosnia and Herzegovina (FERK) per Table 2 [20].

The wind turbine classification in Table 2 by installed power aligns with the Regulation on encouraging renewable energy and efficient cogeneration production and incentive fees ("Official Gazette of the Federation of B&H " number 48/14). It also follows the Rulebook on acquiring qualified electricity producer status ("Official Gazette of the Federation of B&H" number 53/14). Table 2 shows investment costs, O&M costs, as well as the guaranteed purchase price of electricity depending of the size of the wind power plant, valid from September 1, 2020. The category to which the wind farms analysed in this paper belong, whose power ranges from 36 to 50,6 MW, is marked in gray in Table 2.

Wind farms	Power	Specific value of the investment	O&M costs	Fuel costs	Reference price of electricity	Guaranteed price
	kW	€/kW	€/kW	€/kWh	€/kWh	€/kWh
Micro	23	1.417	115	0	0,0645	0,1177
Mini	150	1.417	61	0	0,0645	0,0963
Small	1.000	1.331	34	0	0,0645	0,0809
Medium	10.000	1.171	22	0	0,0645	0,0682
Large	> 10.0000	1.112	20	0	0,0645	0,0645

Table 2. Guaranteed electricity purchase prices valid from September 1, 2020. [20]

Studies [21], [22] and [23], were utilized to determine the unit cost of the investment as well as the operation and maintenance expenses. The studies found that the unit price of wind power plants, depending on the size of the plant, ranges from 1110 €/kW to 1.415 €/kW, while the operation and maintenance costs range from 20 €/kW for large plants to 115 €/kW for micro plants.

All wind farms built so far in B&H generate revenue by selling electricity at contracted and guaranteed purchase prices, known as feed-in-tariffs. To determine the guaranteed purchase prices, the form of primary energy, the contracted purchase period of 12 years, the technology used, the commissioning date of the plant, and the installed capacity of the plant are taken into account according to FERK. Producers of renewable energy electricity from plants like small hydro power plants, wind farms and solar power plants in the Federation of Bosnia and Herzegovina (FB&H) sign 12-year contracts with utility companies, while contracts in the Republic of Srpska (RS) last for 15 years. Other plants have 5-year contracts. In addition to these benefits, producers also receive incentives for producing so-called clean energy by collecting fees through electricity bills paid by citizens of B&H.

To calculate the net present value (NPV) of energy investment projects, future cash flows must be discounted by the rate of return of comparable alternative investments (the opportunity cost), such as simply depositing funds in banks at a certain interest rate, investing in certain securities or some other more profitable projects. Thus, for investors, the discount rate equals the interest rate generated by investing capital in a certain market segment, including market risk. Per the recommendation of World Bank experts, a 7% discount rate was used for the analyses [24]. Sensitivity analysis can also be done for other discount rate values. It should be noted that this analysis did not account for various incentives and subsidies when calculating LCOE, but taking these into account would further reduce the LCOE for all three wind farms.

4. Results and discussion

The levelized cost of energy (LCOE) represents the electricity price at which revenues equal costs, including return on investment equal to the discount rate. Higher electricity selling prices yield better returns while lower prices incur losses.

Using known data on installed capacity, investment, and estimated annual electricity production for three wind farms in B&H, the LCOE calculation was made. Considering that plants using renewable energy sources for electricity production are capital-intensive technologies, the discount rate will be the factor with the greatest impact on levelized electricity costs. This explains the LCOE differences for similar technologies across the EU. Operation and maintenance costs are estimated as 20 €/kW (20.000 €/MW) for these >10 MW wind farms per in accordance with Table 2. An annual 0,5% escalation rate is applied, although different rates could be used if costs are expected to increase over time. The lifetime of the plant is also one of the input data when estimating the LCOE. The lifetime of the plant is an estimate of how many years a certain plant will be able to work effectively, i.e. bring a revenue. A 25-year lifetime is assumed.

A calculation tool in MS Excel was developed for LCOE assessment purposes. Using the assumed value of the discount rate, the growth rate of operation and maintenance costs as well as the lifetime of the turbines, and based on the available data on the investment, the estimated annual electricity production, the estimated LCOE values for the three wind farms in B&H that are in operation are obtained. The input parameters used for LCOE calculation are presented in Table 3 for all three wind farms as well as the overview of costs during wind farm life cycle which can be extrapolated to other wind farms in Figure 6.

The capital costs of onshore wind power project can be divided into the following categories: the turbine costs including blades, tower and transformer in range from 65% to 84 % of the total investment, construction works including construction costs for site preparation and the foundations for the towers in range from 4% to 16% of the total investment, grid connection costs with share from 9% to 14% and other capital costs with share from 4% to 9% in the total investment which can include the construction of buildings, control systems, project consultancy costs, etc [25]. In this paper, the growth rate of operating and maintenance costs of 0,5% per year is assumed.

Assumptions	Wind farms in B&H		
	Podveležje	Mesihovina	Jelovača
Total Plant Capacity (MW)	48	50,6	36
Initial Investment Cost (€)	77.000.000	82.000.000	40.000.000
Operations and Maintenance Cost (€/MW)	20.000	20.000	20.000
Operations and Maintenance Cost (€)	960.000	1.012.000	720.000
O&M Growth rate (%)	0,5	0,5	0,5
Annual Fuel costs	0	0	0
Annual Electricity Output (MWh)	130.000	165.000	110.000
Project Lifetime (years)	25	25	25
Discount Rate (%)	7	7	7

Table 3. Input data for three wind farms in Bosnia and Herzegovina

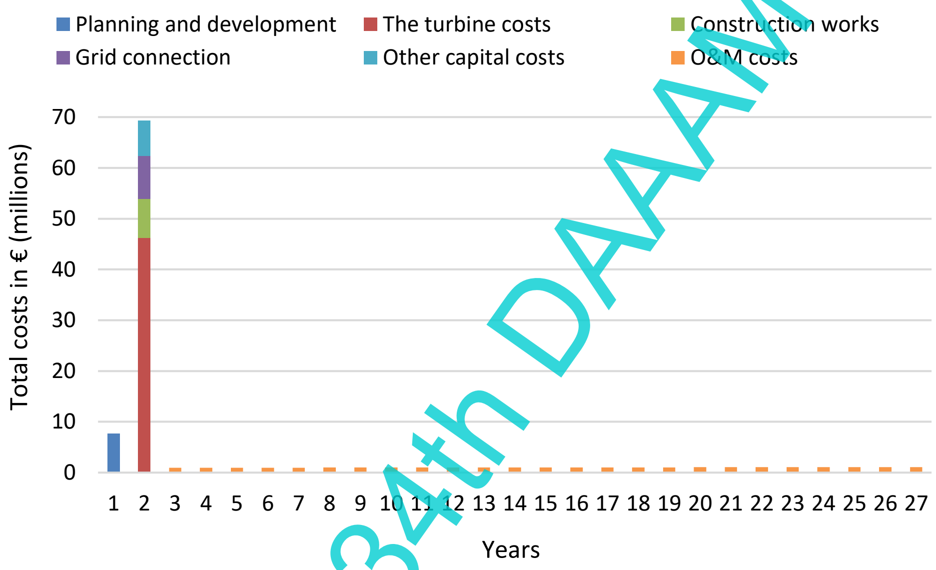

Fig. 6. The overview of costs over the wind farm life cycle

The levelized cost of energy (LCOE) analysis shows that for the Podveležje, Mesihovina and Jelovača wind farms to reach breakeven, where revenue equals expenditures, the electricity price needs to be 62,09 €/MWh, 52,04 €/MWh and 40,23 €/MWh respectively, as shown in Figure 7. These prices align with cost trends in Germany, presented in Figure 1. At these prices, the NPV of each project would be zero.

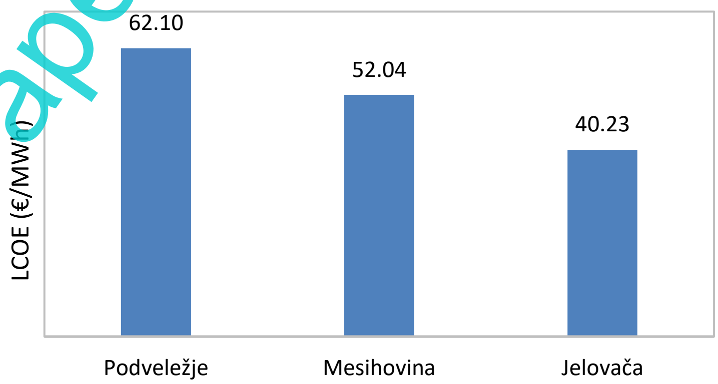

Fig. 7. Estimated LCOE for analysed wind park in €/MWh

The LCOE estimates illustrate that Podveležje has the highest MWh price of 62,10 €/MWh, while Jelovača has the lowest of 40,23 €/MWh. Podveležje's higher LCOE of 62,10 €/MWh compared to Mesihovina's 52,04 €/MWh reflects the differences in their investment costs and energy production. Podveležje has a unit investment of 1.604 €/kW and estimated annual production of 130 GWh. In contrast, Mesihovina has a lower unit investment of 1.620 €/kW but higher estimated annual production of 165 GWh. Jelovača has the lowest LCOE at 40,23 €/MWh because of its substantially lower unit investment cost of 1.111 €/kW, despite its lower estimated annual production of 110 GWh.

Reductions in the LCOE improve the economic viability of wind power plants, while increases in LCOE reduce profitability. Specifically, factors that decrease capital or operating costs, or increase electricity production, reduce LCOE and improve profitability. Conversely, factors that increase capital or operating costs, or reduce electricity production, increase LCOE and reduce profitability. The analysed wind power plants are economically attractive investments because their LCOE is below the government's guaranteed purchase price of 0,0645 €/kWh (64,5 €/MWh). When the LCOE is lower than the guaranteed electricity price, wind power projects can potentially generate profits.

In order to perform a sensitivity analysis of the estimated LCOE for the analysed wind farms, the discount rate, O&M costs, output energy and project lifetime will be individually varied below. Figure 8 shows the variation in LCOE by varying the discount rate in the interval from 1% to 10%. Based on the results shown in Figure 8, it can be concluded that LCOE strongly depends on the variation of the discount rate, i.e. an increase in the discount rate leads to an increase in LCOE, while a decrease in the discount rate results in a decrease in LCOE.

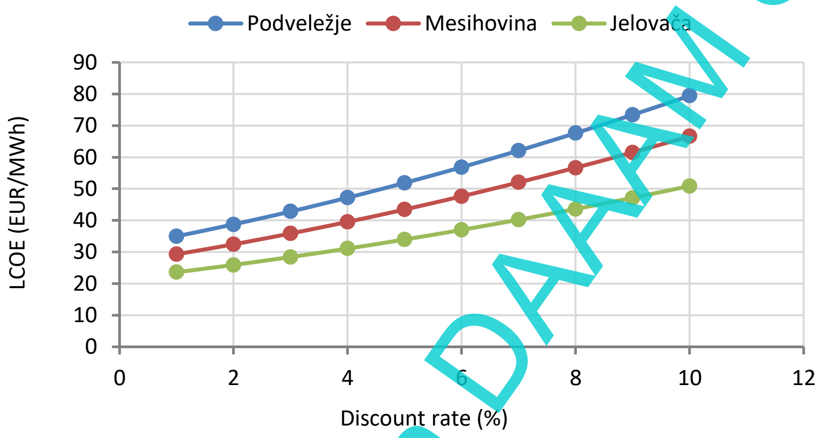

Fig. 8. Variation of the LCOE depending on discount rate

Figure 9 shows the influence of varying plant lifetime on LCOE. The variation was made in the range of 15 to 30 years. Extending the life of the project leads to higher energy production, which affects the reduction of LCOE. In contrast, reducing the lifetime of projects causes a large increase in LCOE.

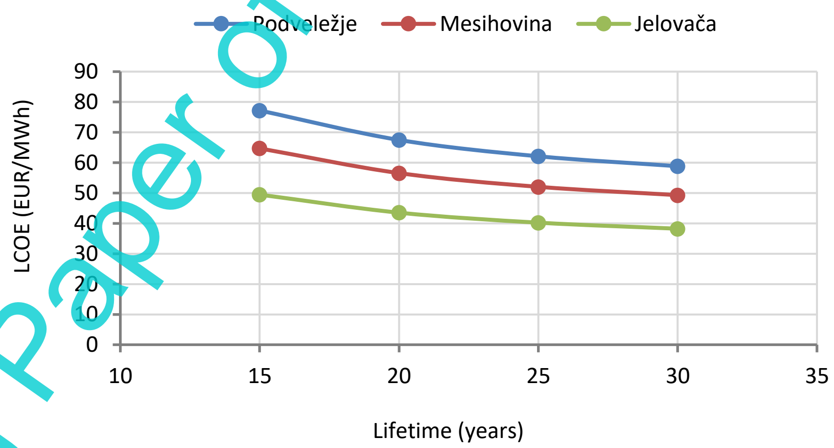

Fig. 9. Variation of the LCOE over the project lifetime

Figure 10 presents the impact of the variation of operation and maintenance costs on LCOE. From Figure 10, it can be seen that for all wind farms, operation and maintenance costs have a very small impact on LCOE. By varying the O&M costs in the range of −60% to +60%, no significant change in LCOE is observed. Such results can be explained by the fact that the share of annual operating and maintenance costs in comparison with the total investment costs for the first years of operation of wind farms is very small and ranges from 1,23% to 1,8%.

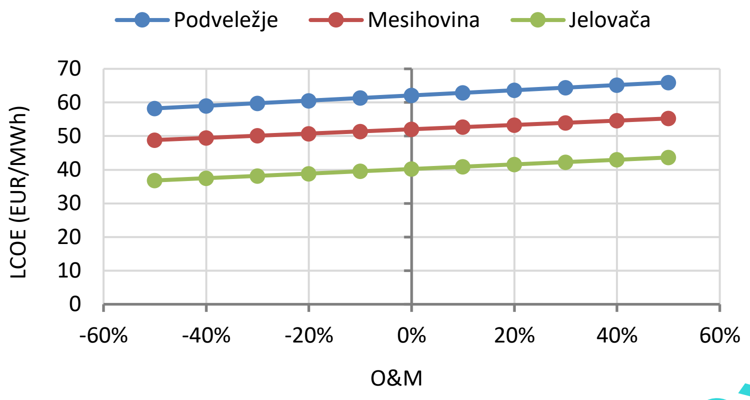

Fig. 10. Variation of the LCOE depending on O&M

Figure 11 shows the dependence of LCOE on output energy. For the analysed wind farms, the produced energy was varied in the range from -20% to +20%. Based on the obtained results shown in Figure 11, it is clear that LCOE decreases with increasing electricity production.

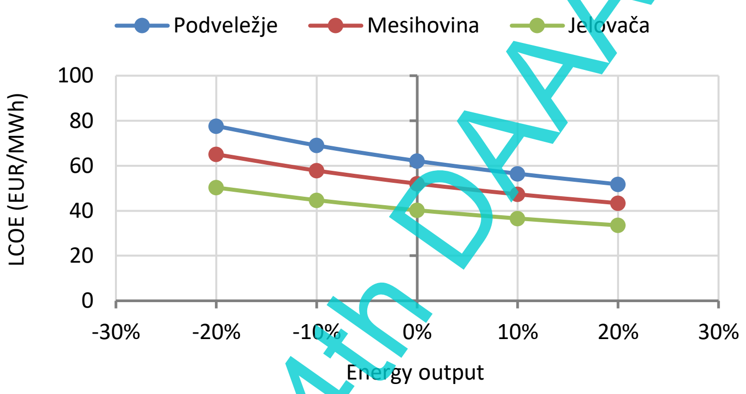

Fig. 11. Variation of the LCOE depending on the electricity production

Two key variables when calculating the LCOE are total plant costs and energy output. Essentially, anything that increases the energy output over the lifetime of the plant and reduces costs results in a lower LCOE. This is why it is very important at the beginning of a wind farm project to thoroughly assess the wind resources in the planned location and optimally position the turbines to maximize annual electricity production.

5. Conclusion and further work

The paper provides an overview of the development of wind farms in Bosnia and Herzegovina from the first constructed wind farm to the present day. It presents data on the total power, estimated electricity production, and total investment for the constructed wind farms. The paper introduces a methodology for calculating the levelized cost of energy (LCOE), which can be applied to plants with different electricity production technologies. Using this methodology, the LCOE was calculated for individual wind farms in Bosnia and Herzegovina, showing the approximate price of electricity produced and its competitiveness with the country reference electricity price. A sensitivity analysis of LCOE to the discount rate, operation and maintenance costs, lifetime, and energy output was conducted.

The results showed electricity production costs for all analysed wind farms are lower than Bosnia and Herzegovina guaranteed purchase price of 0,0645 €/kWh (64,5 €/MWh) for large wind farms. This suggests the government should encourage more wind farm investments as current farms have limited lifetimes, helping energy independence and reducing fossil fuels usage and greenhouse gas emissions. The sensitivity analysis revealed that LCOE is most affected by changes to the discount rate and least by changes to operation and maintenance costs.

As incentives, subsidies, and actual rather than planned annual production were not considered in the LCOE calculations, future research could incorporate this data and compare electricity production profitability across different systems. Also, considering that the LCOE method is often used to compare the costs of energy production from different sources and different electricity generation technologies, it would be of great usage to compare the profitability of electricity production from different production systems in the further research.

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