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Role of Renewables in Energy Storage Economic Viability in the Western Balkans

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Abstract: Given the growing shares of renewable energy sources in the grids, the interest in energy storage systems has increased. The role of pumped hydro energy storage systems as flexible solutions for managing peak and off-peak prices from nuclear and fossil power plants in previous systems is now revitalized in the liberalized systems, with a volatile generation of wind and solar energy. Thus, understanding of the patterns behind the economics of energy storage is crucial for the further integration of energy storage in the grids. In this paper, the factors that impact the economic viability of energy storage in electricity markets are analyzed. The method of approach used in this study considers the electricity market price distribution, full load hours, the total costs of energy storage, and linear regression analysis. Using revenues from arbitraging a 10-megawatt (MW) pumped hydro storage system in the Western Balkans, resulting from the electricity market price distribution and the analysis of the total costs of storage, an econometric model is created. This model shows the impacting factors of energy storage development in the context of the rising renewables sector. Research shows that the previous hypothesis about the integration of energy storage systems in proportion to the increase in shares of renewables in the grids is incorrect. There is a significant correlation between energy storage revenues, the dependent variable, and the independent variables of hydro, wind, and solar generation. The conducted analysis indicates the future arbitraging opportunities of pumped hydro energy storage systems and provides useful insights for energy storage investors and policymakers. During the transitional period, until the deployment of renewables changes the effects of fossil power plants, energy storage price arbitrage is profitable and desirable for 500, 1000, and 2000 full load hours in the Western Balkan region. Despite the need for flexibility, with more renewables in the grids, large-scale energy storage systems will not be economically viable in the long run because of "revenue cannibalization".

Keywords: energy storage; renewable energy sources; electricity market; profitability

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1. Introduction

Since the beginning of the 20th century, pumped hydro power plants have been used for the mitigation of the demand and supply imbalance. When energy systems consisted of fossil and nuclear power plants, turning on and off power plants during scarce demand was operationally risky and costly. Hence, pumping water from pumped hydropower plants during off-peak demand and generating electricity during peak demand was an adequate method for ensuring a balanced and cost-effective system. Over the years, energy systems have changed, and, with the expansion of renewables, new issues have emerged. As renewable generation increases in the grids, the stability is threatened, and the additional flexibility that pumped hydro storage provides is needed. When compared to the previous systems, the shares of renewables in the final energy consumption in Europe significantly increased from 6.8% in 1990 to 19.9% in 2020 [1]. This increase resulted from lower technology costs, government subsidies for energy policies, and feed-in tariffs. The Paris Agreement, as an international treaty on climate change to limit the temperature increase to 1.5 °C above pre-industrial levels, ensures that the development of renewables continues. Renewables' target shares are determined within national energy and climate action plans (NECPs), defined by the signatory countries. As the new International Energy Agency's outlook predicts, "renewables are set to contribute 80% of new power capacity to 2030 in the Stated Policies Scenario" [2], underlining future changes in the energy sector. The transition to the decarbonized energy system in Europe has been determined by the Green Deal, which aims to achieve zero net emissions of greenhouse gasses by 2050, making it the first climate-neutral continent. This has been determined within the set of proposals regarding the climate, energy, transport, and taxation policies adopted by the European Commission in 2024. The set target for reducing the greenhouse gas emissions by 55% by 2030 has recently been increased, as one of the goals of the 28th conference of the Convention on Climate Change (COP28). The participants signed the Global Renewables and Energy Efficiency Pledge, committed to triple the world's installed renewable energy generation capacity to at least 11 terawatts (TW) by 2030 [3]. All of these policies and plans for greenhouse gas mitigation impact electricity markets. Balancing energy systems with the installed intermittent renewable generation requires additional flexibility. Pumped hydro storage (PHS) systems were already an important tool in dispatching and balancing electricity demand/supply. Today, they are considered valuable market players for ensuring balanced and carbon-neutral systems, along with other energy storage systems (ESSs), such as batteries, compressed air energy storage, or hydrogen. Detailed techno-economic reviews of energy storage [4,5] highlight the importance of energy storage costs in further energy storage grid integration. They show that PHS is currently the most cost-effective technology. Pumped hydro storage has low greenhouse gas emissions potential, as it can be constructed to have a minimal environmental effect, as analyzed in [6]. The authors describe options for the development of PHS, addressing the existing environmental concerns and proposing the tools for sustainable PHS development, despite their geographical constraints.

The core objective of this paper is to analyze the relationship between energy storage revenues and hydro, wind, and photovoltaics (PVs) generation and the European Union Emission Trading Scheme (EU ETS) prices, i.e., the fundamental drivers behind the economic viability of energy storage. The selected renewables represent the substitute for fossil generation in the Western Balkans (WB). An econometric model is used to analyze the revenues obtained from arbitraging a 10-megawatt (MW) pumped hydro storage system, considering the distribution of electricity market prices and the total costs of storage. The results indicate the impacting factors of energy storage development in the context of rising renewables.

Given the current state of the art, energy storage systems and renewable energy sources (RES) have been closely related and considered as key factors in future carbon-free systems. Among the many services provided by energy storage systems to support the RES integration in the power grids, described in detail by [7–9], are flexibility and the resolution of RES intermittency. As more renewables are in the grid, more energy storage is needed. This hypothesis is questioned in various papers, where different methods of analysis are provided. In [10], an assessment of energy storage capacity for up to 100% renewable generation in the analyzed study case is based on the net-demand profiles, which are the result of subtracting the wind and solar profiles from the profile of electricity demand. The algorithm calculates the capacity of energy storage based on these profiles, as they present periods of negative demand, when renewables exceed the electricity demand, and periods of positive demand, when additional energy is required. The results show that the energy storage systems' rated power would increase with the penetration of renewables in the grids. Similarly, the optimization analysis in [11], which minimizes operational and replacement costs of the energy systems used to cover demand with a specified share of RES, reveals that the optimal capacity to deal with RES intermittency exponentially increases as the decarbonization targets increase. If the development of renewables is expected, then the development of energy storage technology and a decrease in its costs are also expected [12]. Research by [13], based on a cost-based capacity analysis, reveals that a decarbonized power system, in the analyzed case study of Italy, can be reached with lower costs if energy storage is implemented. The decision layers of the power system are optimized in the model, with the objective function of minimizing the planning and operation costs of the power system based on the input parameters, such as the available generation technologies and load requirements. If batteries were installed, the total costs of energy generation would increase by 20% instead of 40%, since system operation is less expensive with ESS because it allows for more RES generation. Similarly, the expansion model in [14] is based on the cost-minimal generation and storage capacities of pumped hydro storage, allowing for their optimal dispatch when different shares of RES are considered. The analysis shows the RES and ESS complementarity, but they can also be substitutes, as ESS can be replaced by RES curtailment. Ultimately, it is shown that 100% of RES shares will increase the role of long-term storage. Considering the geographical locations of PHS as their main constraints, there is an acceleration of research regarding short-term storage, especially regarding the use of Li-ion batteries for large-scale applications. Cost-optimal generation and storage analysis [15] finds Li-ion batteries still expensive, as they cover only 4% of peak demand when there is an increase of 40–60% in renewables. The value of storage is estimated based on the balance of the system, i.e., the changes in transmission and generation costs of energy systems when additional units of storage are added. The optimization and regression analysis of large-scale batteries for price arbitrage [16] also finds negative profits in the current electricity market conditions. All the relevant research agrees that energy storage is a vital element for reaching the set targets in the implementation of RES, but a decrease in energy storage costs would enable a faster transition towards a sustainable energy sector [17]. For the further development of renewables, it is important to plan the installation of a new energy storage system along with the renewable energy sources, considering relevant application and storage capabilities [18,19]. As found in [20], PV prosumers with batteries can lower costs and reduce dependency on large-scale centralized grids. Because of the variable nature of RES, higher shares impact electricity market conditions and prices significantly, hence, price arbitrage is considered a valuable tool for the mitigation of these effects. Arbitrage is a profitable and effective method for managing demand and supply. When prices are higher, ESSs discharge and sell electricity, while when prices are lower, ESSs charge and buy electricity from the market. This paper contributes to the investigation of the relationships between energy storage systems for price arbitrage and renewable energy sources. All previous research reveals that energy storage systems are prime and inevitable parts of the future energy systems, but the economics behind them are usually neglected. The conducted econometric model of analyzing the effects of the rising renewables and carbon prices on the revenues of energy storage price arbitrage shows the economic viability of energy storage systems when developed alongside renewables.

The main contribution of this paper is the analysis of revenues resulting from the average prices in the electricity market's hourly day-ahead price distribution. This analysis concerns different factors, including hydro, wind, PV generation, and EU ETS prices. This approach, used for the Western Balkan scenario, where renewable generation is yet to be fully developed, is a valuable addition to the previous research on renewables' impact on the energy storage systems' development. Considering the lack of research regarding energy storage in the Western Balkan countries and the lack of investments in renewables, we have chosen Western Balkans as a case study for the analysis.

The core objective of this paper is to analyze the relationships between energy storage revenues and the generation of hydro, wind, and PV solar renewables. This paper is structured as follows: Section 2 presents the development of renewables in Western Balkan countries. Section 3 presents the method for the conducted analysis. Section 4 presents the effects and impacting factors on energy storage profitability, considering the prospects of energy storage. Section 5 gives an overview of the obtained conclusions.

2. Renewables in the Western Balkans

Understanding the dynamics between the growing shares of renewables in the electricity market and energy storage revenues is crucial for future investments in the energy sector, given the obligations stemming from agreed energy and climate targets. Almost half of the demand in the Western Balkan region is covered by hydro run-of-river or accumulation, with modest generation from wind and solar sources, which is almost non-existent when compared to hydro. The share of hydro in total electricity demand represents 30%, while the shares of wind and solar are less than 3% (Figure 1). This scarcity of generation from PVs and wind is due to the high dependency on fossil generation in the WB region. Over the years, there has been a development of energy policies and legislation, as Western Balkan countries represent six of the contracting parties of the Energy Community (Albania, Bosnia and Herzegovina, Kosovo, North Macedonia, Montenegro, and Serbia) obliged to establish and develop an integrated pan-European energy market with the European Union (EU). A Declaration on Energy Security and Green Transition [21] has been signed by the leaders of WB as an additional pledge to align energy sectors with the international commitments established within the Paris Agreement and The Energy Deal. The WB region has been heavily dependent on coal, with inadequate regulation and underinvestment in renewable energy sources. The implementation of day-ahead and intraday coupling is an inevitable requirement for integrating WB countries into the EU's internal electricity market. The region consists of different exchanges, including SEEPEX in Serbia (operational) and the soon-to-be-launched new trading platforms MEPX in Montenegro, ALPEX in Albania, and MEMO in North Macedonia. Still, these single platforms are subject to volatility; hence, the Hungarian Derivative Exchange (HUPX) is used for the analysis (Figure 2).

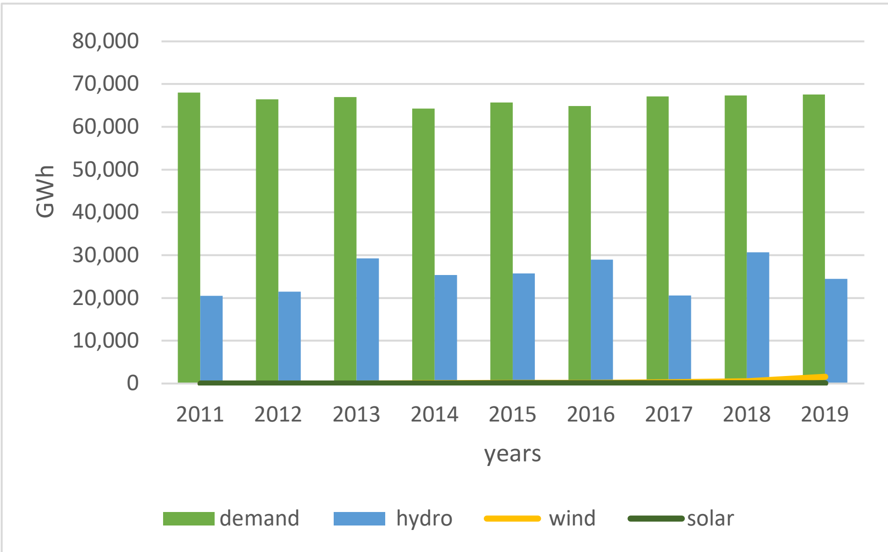

Figure 1. Total generation of selected renewables in the total electricity demand over the years for the Western Balkan region [22].

The energy transition has been long underway, but not as effectively as expected. With the energy crisis, when gas shortages in Europe imposed high electricity prices in 2021 and 2022, countries dependent on fossil power plants continued to generate electricity, despite technical and mining problems. These problems are the consequences of the powerplants' age, with the installations dating back to the fifties, and of the decrease in coal quality. The unfavorable weather conditions, when hydro generation was scarce, and the increased imports, combined with the soared electricity prices, heightened these effects. Higher electricity prices impact the usage of fossil power plants and delay their phasing out, although wind and PV investments have been simultaneously increasing [23]. Bearing in mind the above-mentioned effects of the energy crisis, despite committing to the achievement targets by 2030 (Table 1), the Western Balkan countries continue using fossil power plants to their maximum extent, hence, prolonging the committed development of the RES, even at the expense of environmental and social consequences.

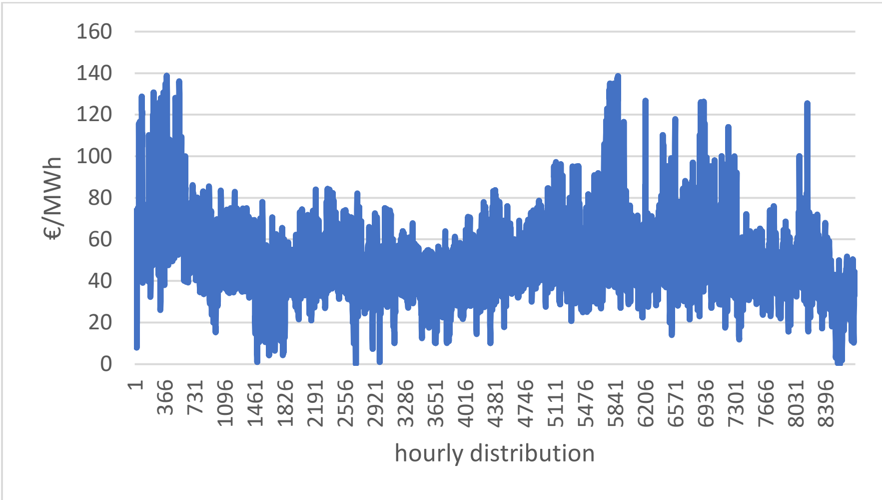

Figure 2. Actual day-ahead hourly price spread of the HUPX electricity market in 2019.

Table 1. Targets for share of energy in gross final energy consumption [24].

Contracting Party	2020 Targets of Energy from RES in Gross Final Energy Consumption	2030 Targets of Energy from RES in Gross Final Energy Consumption
Albania	38%	52.0%
Bosnia and Herzegovina	40%	43.6%
Kosovo	25%	32.0%
Montenegro	33%	50.0%
North Macedonia	21%	38.0%
Serbia	27%	40.7%

Although these targets are well established, aligning with the NECPs, countries are still lagging behind the RES investments. The main constraints are regulatory uncertainties and limited regional market integration [25]. As of 2023, the Energy Community reports that Albania and Montenegro have managed to surpass the 2020 RES targets; Serbia and Bosnia and Herzegovina came close to reaching them, while North Macedonia and Kosovo stayed below the set targets [26]. The biggest share for reaching the set targets comes from hydro generation as renewable hydropower, accounting for 92% of the total renewable energy production in 2019 [27]. All countries, except for Albania, are dependent on coal and are continuing to use it despite their high wind and solar potential. The European Union's (EU) planned Carbon Border Adjustment Mechanism (CBAM) is expected to minimize this coal dependency, as it will apply imposing charges on electricity imports from carbon-intensive industries in the upcoming years. The price of European Union (EU) carbon emission allowances has been increasing over the years, as free allocation has been reduced (Figure 3). Decarbonization will lead to the replacement of fossil power plants with PVs and wind, as hydropower expanding potential is limited. This increase in renewable shares in the electricity markets will create flexibility requirements for storage, which can regulate the intermittent nature of renewables. The region currently employs only two energy storage facilities, i.e., pumped hydropower plants, one in Bosnia and Herzegovina and one in Serbia (Figure 4). Other possible technologies for the future economically viable integration of RES are lithium-ion batteries, thermal storage, and hydrogen, which can reduce the natural gas demand by 50 percent by 2050 [28]. Despite the technical advantages of the aforementioned technologies, they are still new, with higher levelized storage costs when compared to the pumped hydro storage. Because of the cost-effectiveness and historical installations of PHS in the WB region, as future installations of RES also indicate energy storage development, their effects are analyzed. The next section covers empirical observations of the optimal PHS revenues, based on the distribution of hourly day-ahead electricity market prices, to understand the impacting patterns for future storage operators and investors in the region.

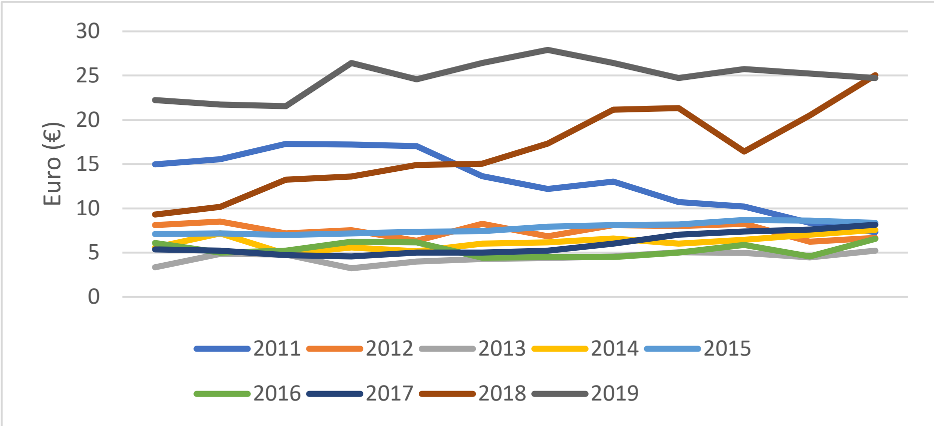

Figure 3. Prices of EU carbon emission allowances over the years for the analyzed timeframe [29].

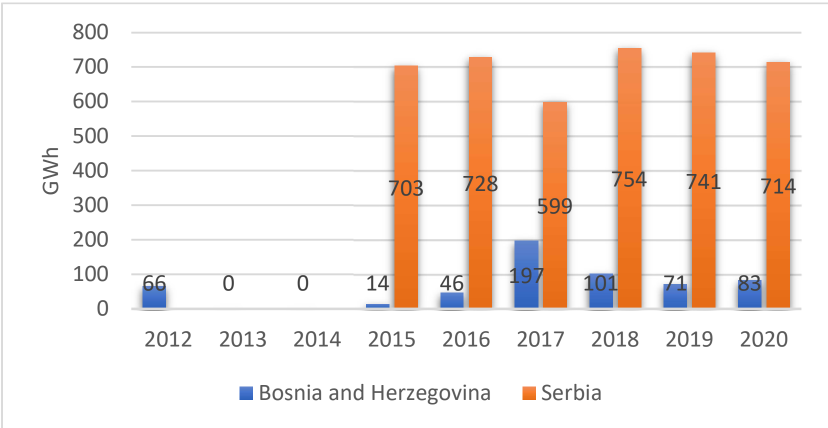

Figure 4. Electricity generation from pumped hydro storage in GWh over the years [27].

3. Method

The renewables' impact on the energy storage development in the Western Balkans is based on the econometric model and revenues and costs analysis. Given the hourly spread of the day-ahead electricity market prices in the period from 2011 to 2019, the average revenues and average costs are calculated depending on a certain number of full load hours. Next, the total production costs of energy storage are calculated based on the work from [30,31], as reflected in the Equations (1)–(4) and Table 2.

$$C_{sto} = C_{cap} + C_{O\&M_a} + C_e \quad (1)$$

where

C_{sto}: total production costs of storage in €/kWh;
C_{cap} : capital costs in €/kWh;
$C_{O\&M_a}$: annualized operation and maintenance costs in €/kWh;
C_e: energy storage costs in €/kWh

$$C_{cap} = \frac{IC_o \cdot CRF}{\eta \cdot FLH} \quad (2)$$

IC_o : investment costs in €/kW;

$$CRF = \frac{i\cdot(1+i)^T}{(1+i)^T - 1}\left(\frac{1}{\text{year}}\right) \tag{3}$$

CRF: the capital recovery factor for an interest rate (i) and depreciation time (T)

$$C_{O\&M,a} = \frac{C_{f,a}}{\eta\cdot FLH} + \frac{C_{v,a}}{\eta} \tag{4}$$

$C_{f,a}$: annualized fixed costs in €/kW;
$C_{v,a}$: annualized variable costs in €/kWh;
C_e: average costs based on the full load hours of the day-ahead market price in €/kWh divided by the energy storage efficiency η.

Table 2. Data for the costs calculation [30].

Costs	Pumped Hydro Storage
IC_o in €/kW	1072
i (%)	5
T (years)	50
η	0.8
$C_{f,a}$ in €/kW	4.6
$C_{v,a}$ in €/kWh	0.00022

The resulting revenues from the price spreads during the analyzed timeframe are presented as dependent (response) variables in the econometric analysis. The independent variables (predictors) are the yearly generation of hydro, wind, and solar PVs, depicted in Figure 1, and the EU ETS carbon price (Figure 3). The regression model allows for the analysis of relationships between renewable generation and storage revenues. The next equation describes the proposed method:

$$R_t = \beta_0 + \beta_1\cdot G_{H_t} + \beta_2\cdot G_{W_t} + \beta_3\cdot G_{S_t} + \beta_4\cdot P_{ets_t} + \theta_1 AR_{t-1} + \varepsilon_t \tag{5}$$

where
R_t : revenues in € for the year t, (resulting from the price spread analysis);
β_0 : intercept;
β_1, β_2, β_3, β_4: regression coefficients;
G_{H_t}, G_{W_t} G_{S_t}: yearly hydro, wind, and solar generation in GWh;
P_{ets_t}: the average price of EU ETS emission trading system allowances in € for a year t;
$\theta_1 AR_{t-1}$: first lag of the autoregressive term;
ε_t: an error in each iteration of t.

Analyzing the electricity market day-ahead price, it can be assumed that for the optimal price arbitrage, the energy storage would discharge when the prices are highest, hence, the revenues represent the highest average market prices for different full load hours. Since optimal price arbitrage calls for buying electricity (charging energy storage) at the time of the lowest electricity market price, these costs are represented as energy storage costs C_e. In this model, the complexity behind the operation of real storage operators and dynamics behind daily storage discharge/charge are neglected, as additional inputs and insights from storage facilities would be required, and the paper would be expanded to include a dispatch scheduling analysis. The average revenues, resulting from the hourly day-ahead electricity market prices spread and historical renewables generation, are sufficient for the scope of this empirical research. The Durbin–Watson test, applied in the regression model, shows the effects of autocorrelation. Hence, the first lag term of the dependent variable is included. The aforementioned statistic test uses residuals from the least squares regression set of data to find the best fit and to check for autocorrelation among the residuals.

A detailed description of the autoregressive terms and autoregressive exogenous (ARX) models is given in the work of [32,33]. The conducted analysis assumes perfect foresight, as historical data on electricity prices are available. At the time of the analysis, there was not an additional dataset. Hence, the model captures the period from 2011 to 2019, but the general patterns can be derived from the analyzed timeframe, regardless. Similarly, the model is simplified with the assumption of using a pumped hydro storage of 10 MW power capacity, given the assumed full load hours of 500 (scenario S), 1000 (scenario S1), 2000 (scenario S2), 3000 (scenario S3), and 4000 (scenario S4), rather than using the historical outputs of individual storage power plants. Scenarios S, S1, S3, and S4 are chosen as partitions around the average number of full load hours of the pumped hydro storage [30]. These simplifications allow for the analysis of the impacting factors on storage revenues and the understanding of patterns behind the economics of energy storage. Findings from the research provide useful insights for future energy storage investors and policymakers. The given results provide a meaningful understanding of the economics behind energy storage systems and their relationship with the growing shares of renewables in the grids. The proposed method provides valuable insights into the future trends of energy storage development that can be derived for any case study. Future analysis of different energy systems and storage technology will contribute to the improvement of the model.

4. Results and Discussion

To compare the results for the WB region with an energy system consisting of higher shares of renewables installed, a profitability analysis is also conducted for the Austria case study. The conducted analysis of revenue and total costs for energy storage systems, given the price spread in the two electricity markets, results in the profitability of energy storage, being an indication for further analysis regarding the impact of RES on energy storage.

4.1. Price Spread Effects on Storage Profitability

Given the price spread of HUPX and European Power Exchange (EPEX) electricity markets from 2011 to 2019, average revenues and average costs are calculated for different full load hours (Figure 5). This approach allows for the analysis of energy storage profitability, as average revenues are representative of the electricity market prices during a number of full load hours in which the energy storage is discharging electricity, while the average costs represent the electricity market costs for charging the energy storage during a number of full load hours (Figure 6). The data for EPEX in this paper represent the Austrian electricity exchange, i.e., from the 2011 day-ahead electricity market prices from EPEX SPOT (Deutschland(DE)/Austria(AT)), when the exchange was joint, and the data from the EPEX SPOT AT in 2018 (Figure A1). Over the years, different factors have influenced price spreads in these markets. With the renewables boom from the late 2000s, EPEX electricity market conditions have changed significantly. The zero marginal costs of fluctuating photovoltaics and wind power plants impose a merit-order effect by pushing out the inflexible fossil power plants and thus decreasing electricity market prices. This decrease can lead to negative electricity market prices affecting the stability of energy systems. Energy operators are challenged with the higher generation of renewables in the grids, especially at times of lower demand. When an oversupply of generation from RES collides with low demand, there are different options for managing this imbalance. Consumers are either paid to buy electricity, or they are asked to ramp up demand by power suppliers or power operators. These methods are used to avoid turning off inflexible generation units by systems operators, as they provide stability to the system and cannot be easily unplugged because of technical but also economic reasons. For energy storage suppliers, there is an option to curtail renewable energy sources to avoid further unsteadiness, despite the economic and resource waste. The effects of negative prices, as analyzed in [34], can be minimized using different methods, such as adjustments in the electricity market design, improvements in cross-border capacity, and the development of system flexibility. One of the advantages of the energy storage systems is their flexible application in the grids, which is considered a highly effective method for dispatching volatile and intermittent RES generation. However, this feature should be analyzed from the economic point of view as well. Analyzing solely revenues to determine energy storage's economic viability is not enough, as final profitability also depends on the costs of the operating storage systems. The average revenues and total energy storage costs (as in Equation (1)), regarding full load hours for a given timeframe, are shown in Table 3. Higher electricity market prices in the HUPX are a reflection of energy conditions and energy mixes, which are coal and hydro-dependent. Hence, the revenues are higher as well, which eventually show an indication of profits for the HUPX market when compared to the total costs of storage (Figure 7). For the Austrian scenario, electricity market conditions are impacted by the higher shares of renewables installed over the years (Figure A2) at a faster rate than in the WB region, hence lower electricity market prices, which are in some cases negative (Figure 8). Thus, the average revenues and costs when compared to the HUPX are lower, as seen in Figure 9, for 26% and 16%, respectively, given the 2000 full load hours. As Austria has high generation of hydro, which is dependent on weather conditions, mitigation of peak demand is covered by gas power plants, consequently leading to lower arbitrage opportunities (Figure 10).

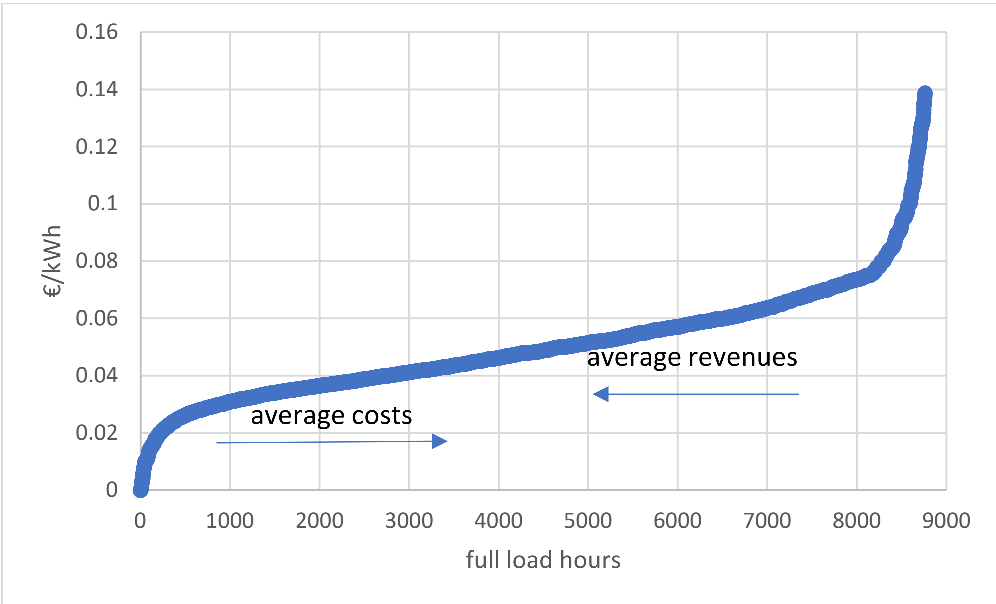

Figure 5. Hourly distribution of the day-ahead electricity prices from HUPX exchange in 2019.

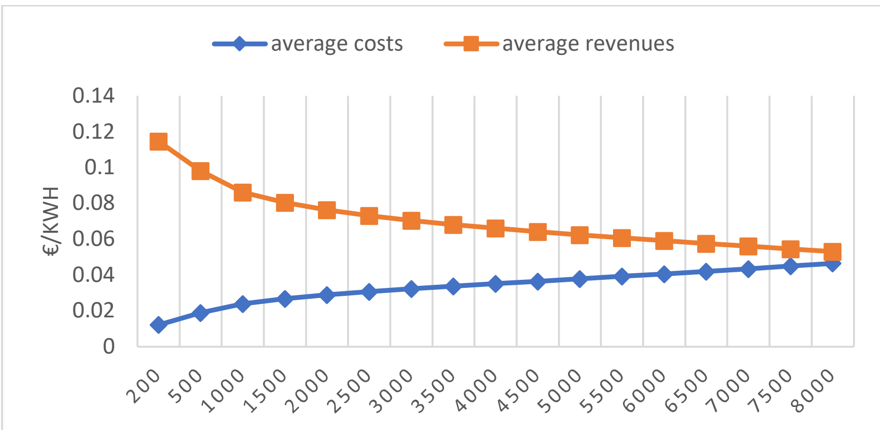

Figure 6. Average revenues and average costs in the day-ahead HUPX electricity market in 2019.

Table 3. Profitability analysis of 10 MW PHS.

Year	Scenario	Full Load Hours	HUPX			EPEX		
			Total Costs €/kWh	Revenues €/kWh	Profit €	Total Costs €/kWh	Revenues €/kWh	Profit €
2011	S	500	0.1831	0.1080	−375,505.8	0.1867	0.0746	−560,734.3
	S1	1000	0.1124	0.0939	−184,849.6	0.1154	0.0713	−440,899.9
	S2	2000	0.0811	0.0816	9606.2	0.0832	0.0676	−312,223.1
	S3	3000	0.0731	0.0756	75,449.0	0.0745	0.0649	−287,519.3
	S4	4000	0.0706	0.0714	31,443.2	0.0712	0.0625	−349,440.6
2012	S	500	0.1705	0.1165	−269,964.2	0.1739	0.0732	−503,892.4
	S1	1000	0.1000	0.1025	25,563.9	0.1018	0.0672	−346,133.8
	S2	2000	0.0691	0.0861	339,957.5	0.0697	0.0616	−161,891.7
	S3	3000	0.0613	0.0773	481,765.6	0.0611	0.0580	−92,708.6
	S4	4000	0.0592	0.0715	489,670.4	0.0581	0.0552	−116,255.7
2013	S	500	0.1670	0.0917	−376,269.3	0.1671	0.0709	−480,867.6
	S1	1000	0.0941	0.0809	−131,596.5	0.0942	0.0655	−287,539.2
	S2	2000	0.0624	0.0707	165,929.9	0.0621	0.0593	−55,458.6
	S3	3000	0.0545	0.0645	300,091.3	0.0536	0.0545	26,800.0
	S4	4000	0.0520	0.0595	302,799.3	0.0506	0.0507	6932.1
2014	S	500	0.1718	0.0819	−449,687.1	0.1663	0.0601	−531,204.9
	S1	1000	0.0982	0.0724	−258,788.7	0.0932	0.0552	−380,203.8
	S2	2000	0.0648	0.0638	−21,069.5	0.0610	0.0496	−227,554.2
	S3	3000	0.0556	0.0589	96,959.8	0.0520	0.0460	−180,905.9
	S4	4000	0.0526	0.0551	101,048.9	0.0483	0.0431	−208,706.2
2015	S	500	0.1743	0.0741	−500,755.6	0.1642	0.0568	−537,011.9
	S1	1000	0.1007	0.0664	−343,438.9	0.0920	0.0527	−393,059.9
	S2	2000	0.0669	0.0602	−135,593.7	0.0596	0.0480	−231,315.3
	S3	3000	0.0577	0.0565	−37,339.5	0.0505	0.0447	−175,438.2
	S4	4000	0.0546	0.0535	−45,034.5	0.0469	0.0419	−197,273.9
2016	S	500	0.1729	0.0641	−544,056.5	0.1625	0.0558	−533,650.9
	S1	1000	0.0986	0.0589	−397,151.2	0.0910	0.0500	−409,660.3
	S2	2000	0.0638	0.0528	−220,944.8	0.0582	0.0439	−286,173.1
	S3	3000	0.0540	0.0490	−150,656.9	0.0486	0.0406	−239,217.8
	S4	4000	0.0506	0.0463	−173,061.5	0.0445	0.0382	−254,309.8
2017	S	500	0.1770	0.1175	−297,564.3	0.1551	0.0771	−390,376.8
	S1	1000	0.1046	0.1002	−44,508.3	0.0862	0.0645	−216,942.8
	S2	2000	0.0716	0.0837	242,347.1	0.0578	0.0544	−69,688.5
	S3	3000	0.0630	0.0751	365,387.8	0.0506	0.0494	−35,771.6
	S4	4000	0.0603	0.0692	356,103.0	0.0478	0.0462	−66,027.3
2018	S	500	0.1760	0.0916	−422,135.4	0.1660	0.0813	−423,547.8
	S1	1000	0.1044	0.0841	−202,922.2	0.0976	0.0758	−218,349.1
	S2	2000	0.0732	0.0765	67,019.7	0.0685	0.0693	16,935.4
	S3	3000	0.0656	0.0716	180,629.8	0.0614	0.0647	97,138.2
	S4	4000	0.0635	0.0675	160,074.6	0.0594	0.0611	64,457.9
2019	S	500	0.1822	0.0981	−420,807.4	0.1722	0.0675	−523,308.5
	S1	1000	0.1092	0.0861	−231,661.1	0.1024	0.0618	−406,093.0
	S2	2000	0.0760	0.0762	4212.8	0.0701	0.0564	−274,594.5
	S3	3000	0.0669	0.0704	103,185.7	0.0609	0.0531	−235,197.0
	S4	4000	0.0639	0.0660	83,747.8	0.0573	0.0505	−271,935.1

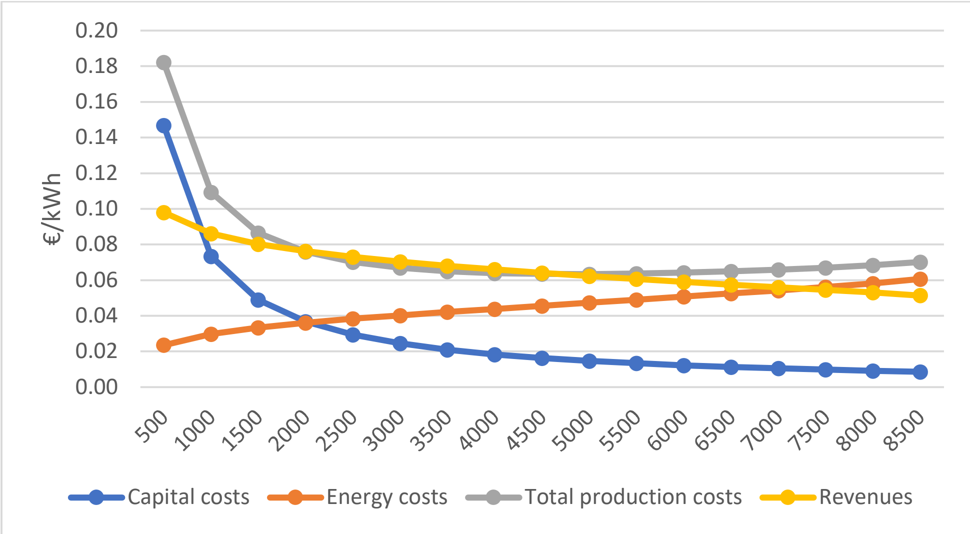

Figure 7. Profitability analysis depending on the different full load hours for day-ahead HUPX electricity market prices in 2019.

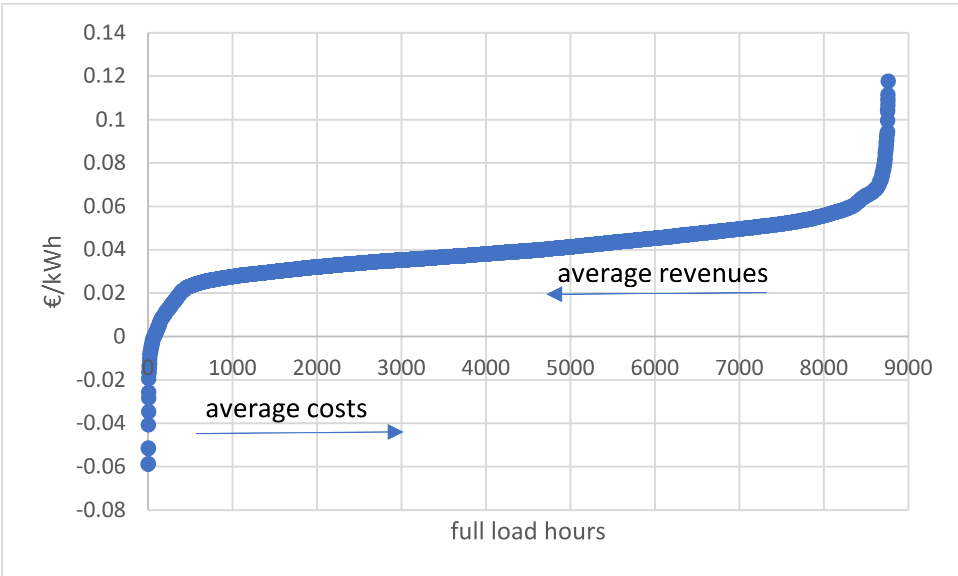

Figure 8. Hourly distribution of the day-ahead electricity prices from EPEX AT exchange in 2019.

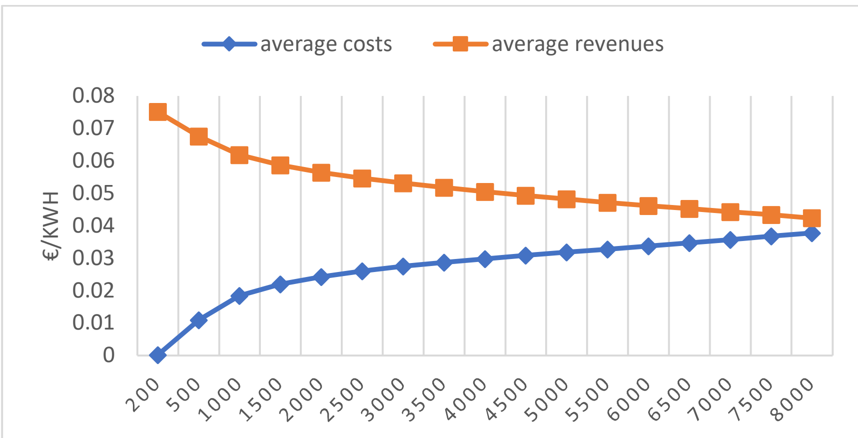

Figure 9. Average revenues and average costs in the day-ahead EPEX AT electricity market in 2019.

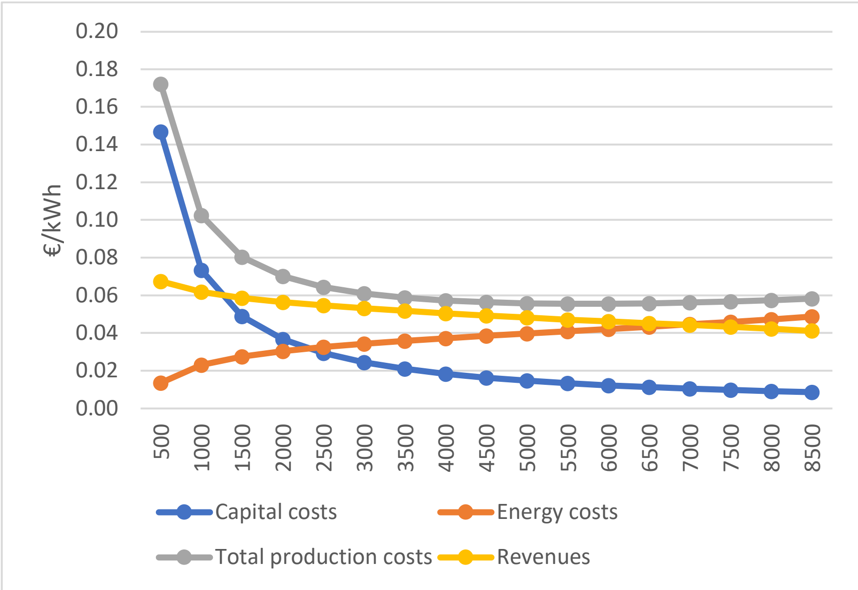

Figure 10. Profitability analysis depending on the different full load hours for day-ahead EPEX AT electricity market prices in 2019.

Scenarios depending on different full load hours are chosen based on the analysis of revenues and total costs, as shown in Table 3. It is evident that in HUPX electricity markets, costs are lower than revenues, in a range from 500 to 4000 full-load hours, indicating profit potential, which is not the case for the Austrian scenario, with profits being positive only above the 2000 full-load-hours threshold and only in exceptional cases during the analyzed timeframe (2013 and 2018). Hence, revenues, serving as changing factors that reflect electricity market conditions, are further used in the econometric analysis for the WB case study, with the ambition to analyze the effects of renewable generation and EU ETS carbon prices on the economic viability of energy storage.

4.2. Impacting Factors on Energy Storage Revenues

The implementation of the Durbin–Watson test for linear regression model indicated autocorrelation in the time-series dependent variable, revenue. With the first lagged terms defined, the linear regression analysis shows signs of high correlation. The correlation matrix (Table 4) presents the relationships among all variables. Almost all coefficients show strong correlations with each other, except for the wind variable and the EU ETS variable, when correlated to hydro generation. The variable hydro generation is correlated to the revenue the most, as was expected, given the described energy system of the WB region. The significance of the model is represented by the *p*-value, indicating whether the null hypothesis can be rejected, while the signs of the coefficients represent the impact of the independent variables on the dependent variable revenue, as shown in Table 5. The independent variables wind, solar, and EU ETS changed their signs in the final output of the linear regression model. This is due to the so-called "suppressor effect" [35], which occurs in this case because the original relationship between the two variables (i.e., wind–revenue, solar–revenue and EU ETS–revenue) is close to zero. Hence, the differences in signs represent random variation around zero. In this case, the signs from the output model (Table 5) should be neglected. Hence, the explanation of the model lies within the original signs, as in the correlation matrix, which confirms the dynamics of the electricity market and energy mix of WB. As hydro and solar generation increases, revenues will decrease. The energy power systems in the Western Balkans consist of mostly fossil and hydro renewable energy sources. Hence, a stronger development of hydro and solar generation can cover peak demands instead of the expensive fossil power plants, lowering electricity market prices. Photovoltaic solar power generates electricity during the day and can substitute for fossil generation power plants at the time of peak demand. Contrarily, wind and EU ETS impact revenues proportionally: if wind generation increases, revenues will increase as well. This is because wind generation is volatile, and it cannot be expected to cover high peak demand. Hence, expensive but flexible fossil generation is used, which will consequently increase electricity prices, eventually leading to more opportunities for storage. It is expected that countries in the WB region will implement CBAM, as only Montenegro has done so far. With carbon taxes, electricity market prices will increase, as generation from fossil power plants will be more expensive. This increase will provide opportunities for energy storage systems. Interestingly, scenarios with lower full load hours are significant for the model. It can be expected that revenues increase with the proposed predictors. For scenarios above 2000 full load hours, the significance of the model cannot be proved. Thus, the model shows that energy storage requirements for the WB region are restricted to 2000 full load hours, and, despite future increases in renewables, energy storage capacity will not increase at the same rate.

Table 4. Correlation coefficients for scenario S in the WB study case.

Coefficients	Revenue	Hydro	Wind	Solar	ETS
Revenue	1	0	0	0	0
Hydro	−0.72451	1	0	0	0
Wind	0.060548	0.049868	1	0	0
Solar	−0.24519	0.244404	0.827332	1	0
ETS	0.180287	−0.01469	0.875327	0.557031	1

Table 5. Resulting parameters of the WB linear regression analysis for the conducted scenarios.

Scenario	Full Load Hours	*p*-Value				R-Squared
		Hydro	Wind	Solar	EU ETS	
S	500	−0.000356 ***	−0.032874 **	0.001063 **	−0.001831 **	0.9995
S1	1000	−0.000511 ***	−0.00354 **	0.001368 **	−0.005242 *	0.9993
S2	2000	−0.03415 **	−0.085058 *	0.070501 *	−0.271771	0.9565
S3	3000	−0.17314	−0.309321	0.330888	−0.831425	0.8098
S4	4000	−0.268517	−0.450408	0.543159	0.831335	0.7323

Note: significance of the *p*-value test: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$; + indicates positive effects, − negative effects.

Linear regression analysis, conducted in Matlab, provides the added variable plots (partial regression plots) that allow for the interpretation of the coefficients when other variables are held constant. These plots show the significance of the model when a horizontal line cannot be drawn between the confidence bounds. In the diagram, the x-axis shows the residuals of the predictors, whereas the y-axis shows the residuals of the response variable, so one can see how all align and move together. The model behind the presented plot is known as the Frisch–Waugh–Lovell theorem, with further details being found in [36]. The narrower the fit, the greater the significance of the model, as it yields R-squared factors greater than 95% for scenarios S, S1, and S2 (Figures 11–13, respectively), harmonizing with the resulting *p*-value from Table 5. As the results show, renewable energy sources impact energy storage development, depending on the design of the energy system. For the analyzed case study, wind generation and EU ETS prices positively affect energy storage revenues. These results are significant market signals for energy storage investors, as a future increase in wind generation is expected in the WB region, along with the imposition of carbon taxes. As for hydro generation and the increased generation of PVs in the region, they will provide the systems with a significant peak covering in the transitional period, until the fossil power plants are fully closed. Further discussion on the future development of energy storage is provided in the next section.

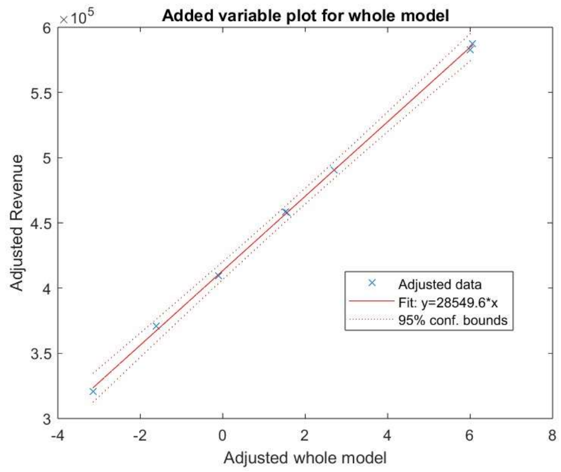

Figure 11. Linear regression analysis for WB region for 500 full load hours.

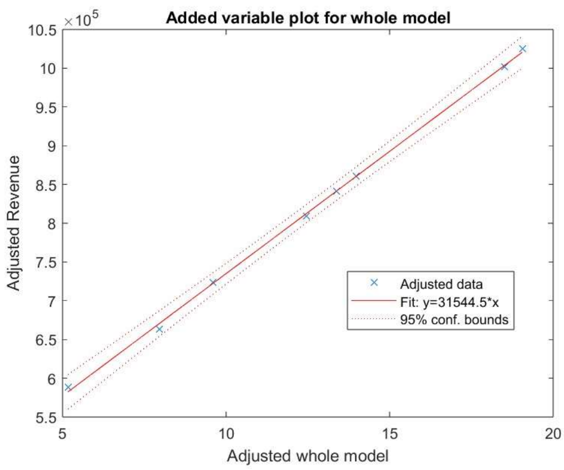

Figure 12. Linear regression analysis for WB region for 1000 full load hours.

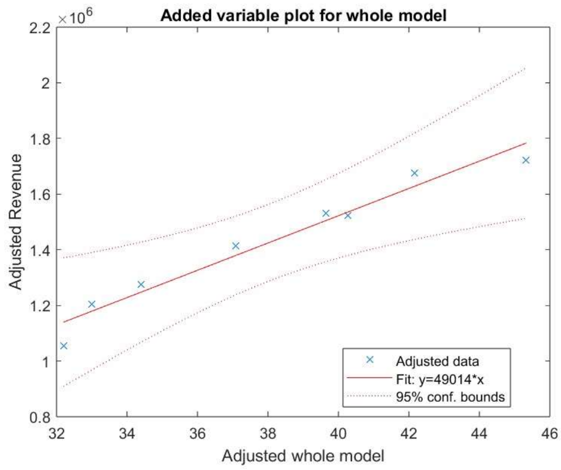

Figure 13. Linear regression analysis for WB region for 2000 full load hours.

4.3. Prospects for Energy Storage

The HUPX electricity market, used as a reference electricity exchange in the Western Balkan region, is highly dependent on fossil generation. In 2019, 72% of electricity generation for the total electricity demand came from fossil fuels (coal, gas, and oil generation) (Bankwatch, 2023 [22]), which illustrates the effects of this generation on the electricity market prices. Hydro generation is also highly dominant in the WB region (Figure 1), used for dispatching processes, with its inflexible fossil generation providing a dose of certainty to the prediction and operation of power grids. It can be expected that these large-scale run-of-river power plants continue their role in the transitional period until the wind and solar shares increase at a higher rate. Together with solar generation, high peak demand can be covered alongside fossil power plants. As these power plants are phasing out, it can be expected that revenues would decrease, which can lead to fewer energy storage arbitrage opportunities. Contrarily, wind generation, which hit electricity markets, especially the EPEX electricity market, with high shares over the last decade, has influenced the overall dynamics of price spreads differently in the electricity market. In wind generation, intermittency and residual demand can be expected, necessitating coverage with higher marginal-cost plants. Hence, revenues, in this case, will increase as well. As expected, the revenues of energy storage arbitrage will increase with the increase of EU ETS prices. The future effects, provided through the conducted analysis, correspond to the predictive results of RES development in the WB by 2050, as analyzed by [37], i.e., "after the initial increase in the electricity prices because of CBAM, effects of RES installment will impact merit order curve after 2040. and lower electricity prices". The modeled approach predicts the highest increase in wind generation, followed by small-scale PVs. It is predicted by [38] that by 2050, the Contracting Parties of the Energy Community have to achieve an increase in renewables by a factor of four, while the highest increase will be from the PVs. These predictions allow for the identification of arbitrage opportunities for storage in the transitional period, as found in the conducted analysis. The analysis shows that the higher RES generation for the WB region will cause an increase in fossil generation in the transitional period, consequently leading to higher price spreads. It can be expected that this trend will continue in the Western Balkan region until there is enough renewable generation and energy storage to support the demand–supply curve. Hence, possibilities for price arbitrage of energy storage systems are justified.

In the EPEX electricity market, an increase in RES generation, which has marginal costs of zero, has displaced gas power plants, which cover peak demand in the merit-order curve, leading to lower electricity market prices. The case of Austria, with more than 80% renewable generation [27] and 24% fossil generation [22], does not demonstrate the profitability of storage, given the analyzed model, when considering their final consumption. This is because the analyzed timeframe costs were higher than revenues in most scenarios for Austria, but considering other events that affect prices, such as a decrease in gas supply or weather conditions, future price spreads cannot be excluded, despite the lower prices. Austria plans to reach 100% renewable generation by 2030, hence, incorporating energy storage or other flexibility options, such as demand–response or imports of electricity, will be inevitable.

4.4. Limitations

The presented approach to the analysis has some limitations. Firstly, the profitability analysis is represented using electricity market price distribution i.e., average revenues. In the dispatching optimization model, these prices would be actual electricity day-ahead market prices, which, along with the energy storage capacity constraints, would yield more precise arbitrage profits. Secondly, as the goal of the paper is to find impacting factors behind storage arbitrage value, the analysis uses the maximum limits of energy storage capacity for the given full load hours, neglecting the energy storage technology constraints. In the optimization dispatching process, storage capacity would be chosen within its limits, with other operational factors considered for price arbitrage (see [16]). Hence, the ultimate profitability is not analyzed, but rather the effects of different factors on the revenues of energy storage in the electricity market.

5. Conclusions

The effects of RES generation on the energy storage systems' economic viability in the WB region are analyzed with the distribution of electricity market prices and full load hours.

Resulted revenues are compared to the total costs of energy storage and implemented in the linear regression model along with the RES generation and EU ETS prices as predictors. The conducted research provided the following conclusions:

- Energy storage development will continue if it is economically viable.
- There is a high potential for energy storage arbitrage in the Western Balkans.
- Wind generation and EU ETS prices impact storage revenues positively.
- Solar generation negatively affects storage revenues.
- Energy storage systems are not economically viable for the long run.

The set hypothesis that more renewables will lead to more energy storage is not entirely correct. Future RES energy systems are inevitable, depending on energy storage, but it is more important to understand the extent and level of profitability at which they will be integrated into these systems. Energy storage systems will be part of the grids if the total costs of storage are lower or if there are additional profits, such as arbitrage or ancillary services. Renewables will continue to provide the system with volatility, which will consequently lead to the need for greater flexibility of the energy systems, such as energy storage systems, but the levels of these investments should be considered in the short and long run.

In the short run, or until Western Balkan countries reach their proposed targets from the NECPs, there is a high potential for energy storage arbitrage. This is due to fossil generation, which is going to be used in the transitional period until RES production is dominant. The reason for this lies in the energy portfolios and dynamics of the electricity markets with inflexible generation.

An increase in wind generation and the implementation of carbon taxes yield higher revenues for storage arbitrage. The future internal electricity market for Southeast Europe is expected to change the overall dynamics in the WB. The region is strongly interconnected; hence, it can be expected that an interconnected electricity market will provide additional benefits for all countries, and with the RES investments along the way, ES plays an important and economically justified role.

Contrarily, the RES generation of hydro and solar decreases revenues, but a significant increase in hydro generation is not expected because the existing hydro potential in the Western Balkans is not going to be expanded, given sustainability and environmental concerns. Solar generation is expected to increase, but it will negatively affect revenues in the short run because the highest generation is during the day, covering the peak demand.

Despite being one of the main factors for a carbon-neutral future, and with the possibilities for profits of up to 2000 full load hours with the future increase of RES in the Western Balkans region, energy storage systems are not economically viable for the long run. Similarly to the merit-order effect of the renewables, as more renewable generation is in the grids, fewer revenues for energy storage will be required due to the so-called "revenue cannibalism" [39]. Although some findings suggest that energy storage, along with other flexibility options, can mitigate the cannibalization effect of RES [14], the type of energy storage technology should be considered. The future of storage also depends on the possible decrease in battery storage costs and technology improvements. Unless electric vehicles and decentralized energy storage systems impose significant changes and provide economically justified flexibility, possibilities for energy storage price arbitrage will decrease with the development of the RES, as the proposed model showed.

The installed energy storage systems do not affect the electricity market prices, but, considering the acceleration in the production of batteries and the changing characteristics of energy storage systems, there is a possibility for future analysis, considering the price-maker approach as well. The effects of the battery storage installed with the PV prosumers in electric vehicles or power-to-gas storage are above the scope of the conducted analysis and represent a subject for future energy storage economic analysis.

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Appendix A

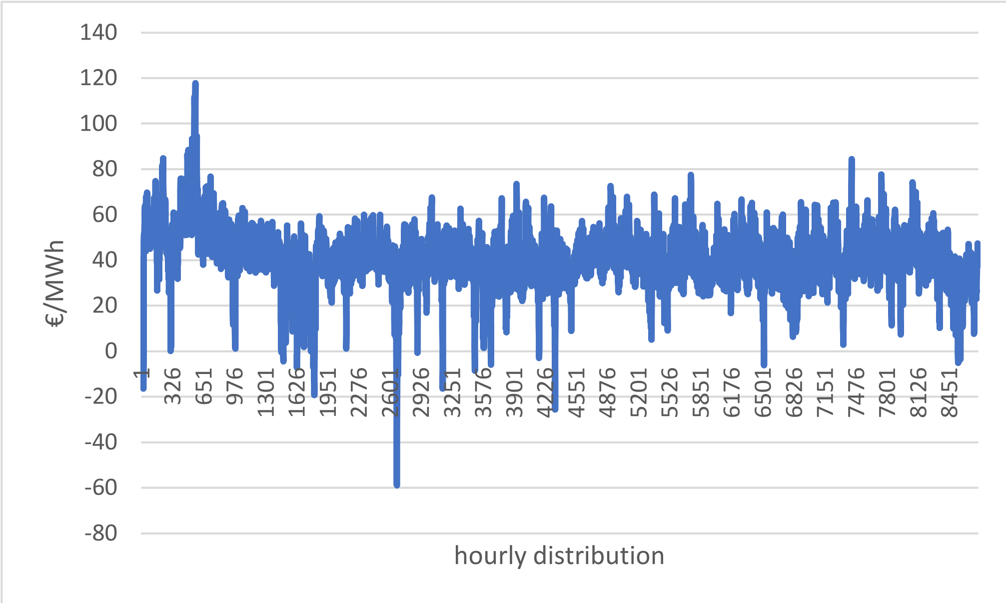

Figure A1. Actual day-ahead hourly price spread of EPEX AT electricity market in 2019.

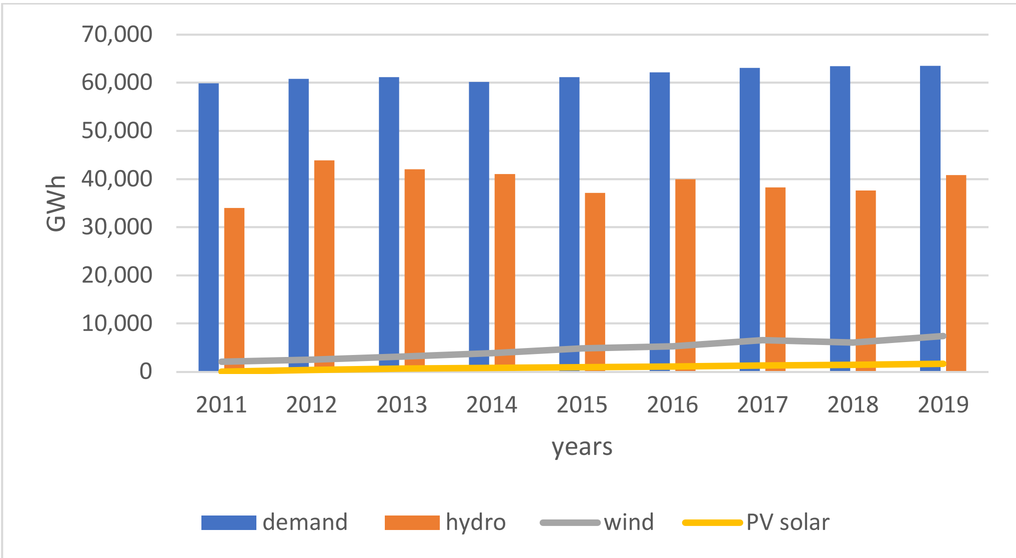

Figure A2. Total generation of selected renewables in the total electricity demand over the years for Austria.

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