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Evaluation of economic profitability using energy storage in context of using renewable energy

Abstract: Energy storage is an increasingly vital aspect of the energy sector in Poland due to the growing prevalence of renewable energy sources. Its primary goal is to support the uptake of renewable energy in the country's energy mix. The article presented here analyzes the economic potential of buying and selling electricity on the Intra-Day Market and the Day-Ahead Market of Towarowa Giełda Energii SA (Polish Energy Market: TGE) in terms of energy storage. In four scenarios, energy was either bought and sold on the DAM/IDM or bought on one market and sold on the other to identify the most favorable case. Two four-month periods in 2021 and 2023 were examined. An analysis was carried out on a lithium-ion storage facility that has a two-hour charging cycle for energy storage. A methodology was proposed to identify the two highest and two lowest energy prices for imposing constraints on the purchase and sale times. The time of day when these prices occurred was also analyzed. The annual and periodic profits that can be obtained by purchasing and selling stored energy were calculated. The calculations and analyses facilitated inter-market comparison. Energy storage payback time was computed, and investment profitability was examined. The final section presents conclusions, opportunities, and suggestions for further research in this area.

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As calculated, the most profitable case after taking efficiency into account was the case of purchase at IDM and sale at DAM in part of 2023: 18,751.61 [EUR/MWh capacity]. In comparison, the highest value for 2021 was obtained for the case of sale and purchase on IDM, with a profit of 7531.23 [EUR/MWh capacity].

Keywords: renewable energy, energy storage, economic evaluation, intra-day market, day-ahead market

Introduction

In recent years, there has been a significant increase in the installed capacity of renewable energy sources. This is in response to increasing demand and price for electricity and to combat climate change (Verzijlbergh et al. 2017). Europe is turning to less carbon-intensive sources (Dellano-Paz et al. 2015; Stecuła 2017; Wojtkowska-Łodej 2016). However, this is associated with less stability in the energy sector due to the variability of hourly energy supply, which is affected by the dependence on parameters such as sunshine and wind (Al-Shetwi 2022).

Therefore, energy storage is becoming an important aspect for which a positive impact on the environment has been proven (Koval et al. 2022; Lin et al. 2016; Sanfélix et al. 2015; Stecuła and Brodny 2017). Storage facilities balance the energy in the system (Dzikuć et al. 2021; Rokicki et al. 2022). They increase the reliability of the energy supply and allow for an increasing share of RES in the country's energy mix. Storage can increase the efficiency of conventional power plants by preventing frequent changes in their operating parameters (Olczak and Matuszewska 2023). Energy storage can also positively impact the electricity system through stabilization, reactive power compensation, frequency, and voltage regulation (Arbabzadeh et al. 2017). It will be possible to compensate for the disconnection of large RES installations at times of low electricity demand.

Energy storage in Poland is not well implemented and developed. The storage system is based on pumped-storage power plants, of which there are few (Lepszy 2020; Ross et al. 2023). It is also difficult to build additional ones due to the large areas they occupy. Storage on a smaller scale is at a much lower level, mainly because of the cost-effectiveness achieved. Lithium-ion batteries are also a very popular energy storage. Various cases of their use have been described in the literature, including an analysis of the cost-effectiveness of using them as energy storage for a single-family house (Filipiak et al. 2022), or for a public building (Terlikowski and Galińska 2022).

Towarowa Giełda Energii SA (TGE) is the only licensed Polish commodity exchange authorized to operate a regulated market. Amongst other things, the exchange operates markets for electricity, natural gas, and CO_2 emission allowances. TGE is the largest in Central and Eastern Europe in terms of electricity trading volumes ("TGE – O TGE" 2023).

The SIDC Intra-Day Market (IDM) operates within the European Union, allowing cross-border trading within it (TGE – SIDC Intraday Market (XBID) 2023). Its development is influenced by the development of renewable energy, for which energy production is not stable over time. It depends on weather conditions such as sunshine and wind. Therefore, there has been an increased interest in this market, where energy can be bought and received when needed. The market provides security in the energy supply in the case of sudden, unexpected changes or outages. With the IDM, entities can sell and buy energy to be delivered on the same day. It also enables short-term sales of electricity (Rogacz 2023a; TGE – SIDC Intraday Market (XBID) 2023; PSE 2023a).

The Day-Ahead Market (DAM) is called an auction market. It has been operating in Poland since 2000. Trading on the Day-Ahead Market takes place one and two days before the energy delivery period. As a result, suppliers have to estimate the amount of energy that can be supplied and the cost a day in advance. Only the best prices offered are taken into account. Merit order is applied to find the lowest possible price for a given hour of the day (14), (PSE 2023b; Rogacz 2023b).

The purpose of this paper is to analyse two markets – IDM and DAM in different years – to comparatively test the potential for economic viability for energy storage. The following periods of relatively stable energy prices in 2021 and 2023 were selected for the analysis (Fig. 1). The highest achievable prices in 2022 were excluded from the analysis as they are unlikely to be repeated year on year in the future.

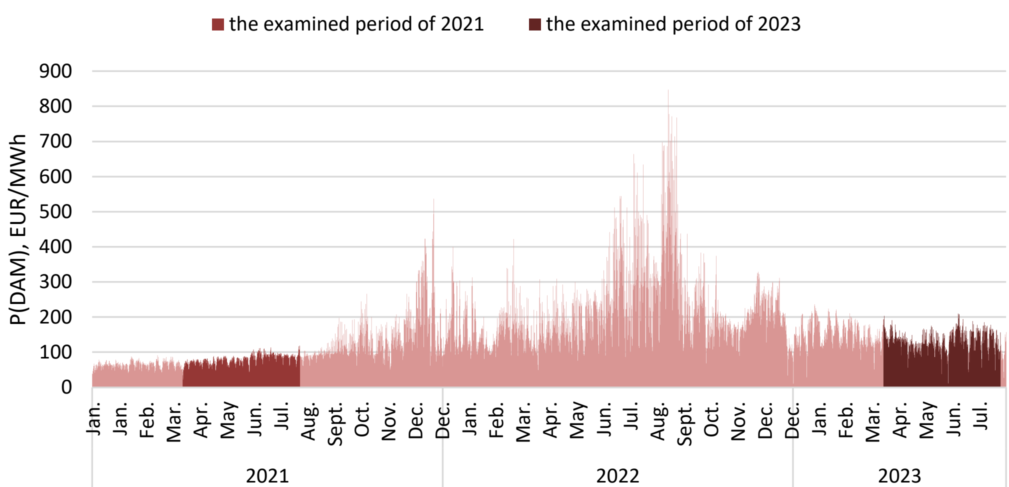


Fig. 1. The course of energy prices on the Day-Ahead Market TGE P(DAM), with analysed periods

Rys. 1. Przebieg cen energii elektrycznej na Rynku Dnia Następnego TGE P(DAM), z zaznaczonymi analizowanymi okresami

1. Methodology

As part of the analysis to test the economic potential of energy storage, operations in two energy markets were considered: Day-Ahead Market and Intra-Day Market. Four scenarios were created for the buying and selling of electricity within these markets. The cases of transactions within one market, buying in one market, and selling in the other were tested.

Selection of cases for different markets:

$$ma.=\{DAM, IDM, DAM \rightarrow IDM, IDM \rightarrow DAM\} \quad (1)$$

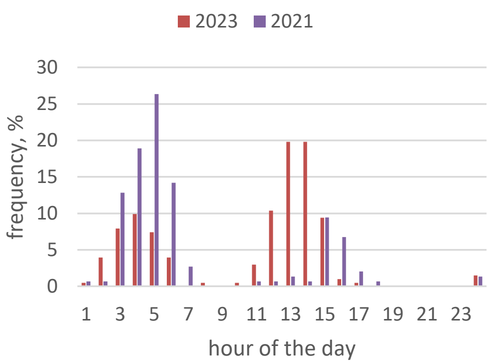
where:

ma. – case of market purchase or sale
DAM – day-ahead market
IDM – intra-day market
DAM → IDM: purchase of energy on the DAM, sale on the IDM
IDM → DAM: purchase of energy on the IDM, sale on the DAM

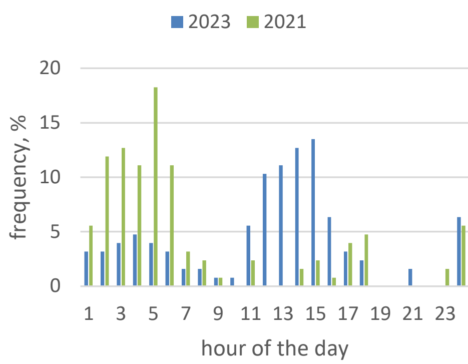
The case study used a two-hour charge and discharge cycle of an energy storage device consisting of lithium-ion batteries. This was done by averaging the two lowest and two highest values to determine the average prices of potential purchases and sales. These averages were then taken into account in the calculation of the total daily operating profit.

Selection of purchase and selling time (hours) and prices for one day:

For the analyzed periods, hourly ranges were selected to check the minimum and maximum prices. This resulted in sets of prices for each day and market (Figs. 2, 3):



a)



b)

Fig. 2. Frequency of minimum prices for: a) Day-Ahead Market, b) Intra-Day Market

Rys. 2. Częstotliwość wystąpień minimalnych cen dla: a) Rynek Dnia Następnego, b) Rynek Dnia Bieżącego

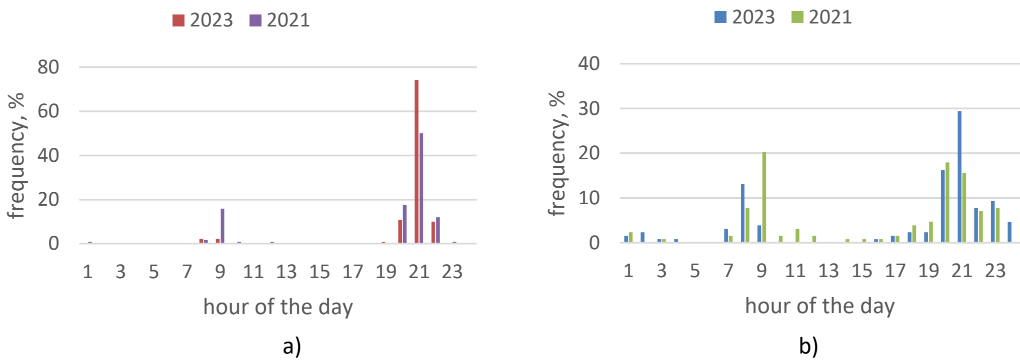


Fig. 3. Frequency of maximum prices: a) Day-Ahead Market, b) Intra-Day Market

Rys. 3. Częstotliwość maksymalnych cen: a) Rynek Dnia Następnego, b) Rynek Dnia Bieżącego

By analyzing the incidence of minimum prices for the day-ahead market and the intraday market for the two periods, it can be seen that the different markets and years differ. The Day -Ahead Market has two peaks, one at night and one in the middle of the day. Their occurrences in 2023 are significantly different from 2021. This is due to the increasing popularity of renewable energy sources, especially photovoltaic panels, for which the highest energy production occurs precisely between 12:00 and 15:00. The occurrence of minimum prices at night is due to the low demand for electricity caused by the low human activity (in households) during these hours.

In the intraday market in 2021, the occurrence of minimum energy prices decreased mainly during the night hours. Also, a large amount was shifted to the hours between 11:00 and 17:00.

Therefore, after analyzing the charts above, the hourly range in which the electricity is purchased was chosen:

$$vP1 = P\left(h \in \langle 1;16 \rangle\right) \tag{2}$$

The choice of range was dictated by the occurrence in 2021 of 84% of cases for IDM and 96% for DAM. In 2023, it is already 87 and 98% of cases.

The frequency of peak prices (Figure 3) also varies between markets and years. The day-ahead market shows a definite predominance of peak prices during the evening peak, especially in 2023, with the highest number of occurrences between 20:00 and 22:00, with over 70% of occurrences at 21:00.

On the Intra-Day Market, the occurrences of maxima are more staggered. Many of them occur in the morning hours. However, the vast majority are contained between 20:00 and 24:00. In 2021, the morning peak was more pronounced; in 2023, the occurrence of price maxima shifted significantly towards the evening peak in electricity demand.

Considering both markets during their respective periods, the following analysis examines the potential selling price range as:

$$vP2 = P\left(h \in \langle 17;24 \rangle\right) \tag{3}$$

where:

P – a set of hourly price values for a particular market, day, and year.

This range in 2021 accounted for 59% of cases for IDM and 80% of cases for DAM. In 2023, there was a significant increase in the share to 74% and 96%.

The values were sorted in descending order at particular hourly intervals.

$$svP1 = sort\left(vP1\right) \tag{4}$$

$$svP2 = sort\left(vP2\right) \tag{5}$$

Selection of the two lowest price values:

$$minP = svP1\left[16\right] \tag{6}$$

$$min2P = svP1\left[15\right] \tag{7}$$

Selection of the two highest price values:

$$maxP = svP2\left[1\right] \tag{8}$$

$$max2P = svP2\left[2\right] \tag{9}$$

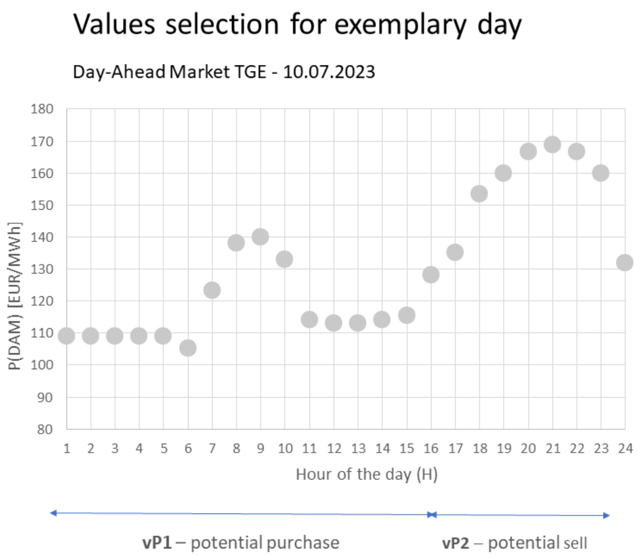
Graphical representation of the selection algorithm (Fig. 4):

The maximum mean daily price of a potential sale in the market has been determined then:

$$maxmP\left(ma.,y,d\right) = \frac{maxP\left(ma.,y,d\right) + max2P\left(ma.,y,d\right)}{2} \tag{10}$$

where:

$maxmP(ma., y, d)$ – the maximum mean daily price of a potential sale,
$ma.$ – market, for example, DAM or IDM,
y – year,
d – day,
$maxP(ma., y, d)$ – the maximum price in the tested time interval,
$max2P(ma., y, d)$ – the second highest price of the period under review.



H	svP1	
9	140	
8	138.22	
10	133.09	
16	128.16	
...	...	
5	109.12	
3	108.89	
4	108.89	min2P
6	105.31	minP

H	svP2	
21	169.89	maxP
20	166.67	max2P
22	166,58	
19	159.79	
23	159.79	
18	153.33	
17	135.15	
24	131.98	

Fig. 4. The selection algorithm of maxP, max2P, min2P, minP

Rys. 4. Algorytm wyboru maxP, max2P, min2P, minP

In addition, the minimum mean daily price of a potential sale of electricity on the market has been determined:

$$minmP(ma., y, d) = \frac{minP(ma., y, d) + min2P(ma., y, d)}{2} \tag{11}$$

where:

minmP(*ma*., *y*, *d*) – the minimum mean daily price of a potential sale,
minP(*ma*., *y*, *d*) – the minimum price in the tested time interval,
min2P(*ma*., *y*, *d*) – the second lowest price of the period under review.

Determination of unit profit for maximum and minimum daily price value:

$$UP(ma., y, d) = maxmP(ma., y, d) - \frac{minmP(ma., y, d)}{\eta} \tag{12}$$

where:

UP(*ma*., *y*, *d*) – the unit profit for the maximum and minimum daily price value,
maxmP(*ma*., *y*, *d*) – the maximum mean price of a potential sale,
minmP(*ma*., *y*, *d*) – the minimum mean price of a potential sale,
η – total efficiency of the storage process.

Determination of daily operating profit:

$$DP(ma., y, d) = \begin{cases} UP & if\ UP \geq 0 \\ 0 & if\ UP < 0 \end{cases} \quad (13)$$

where:

$DP(ma., y, d)$ – daily operating profit,
UP – the unit profit for the maximum and minimum daily price value.

Calculation of period profit:

$$PP(ma., y) = \sum_{d=d_1}^{d_2} DP(ma., y, d) \quad (14)$$

where:

$PP(ma., y)$ – period profit,
d_1 – April 5,
d_2 – August 4,
$DP(ma., y, d)$ – daily operating profit,
d – day.

Estimation of annual profit:

$$YP(ma., y) = \frac{PP(ma., y)}{122} \cdot 365 \quad (15)$$

where:

$YP(ma., y)$ – yearly profit,
$ma.$ – market: DAM or IDM,
y – year.

2. Results and analysis

2.1 Results for 2023

✦ Purchase and sale on the Day-Ahead Market

Figure 5 shows the course of electricity prices quoted on TGE, for three chosen weekdays within the researched period.

The chart differentiates between the possible buying and selling prices of electricity. It shows that on the day in question, the value increased during the morning peak, which means that *maxP2* is not the second-highest value considered that day. This is due to the assumptions given

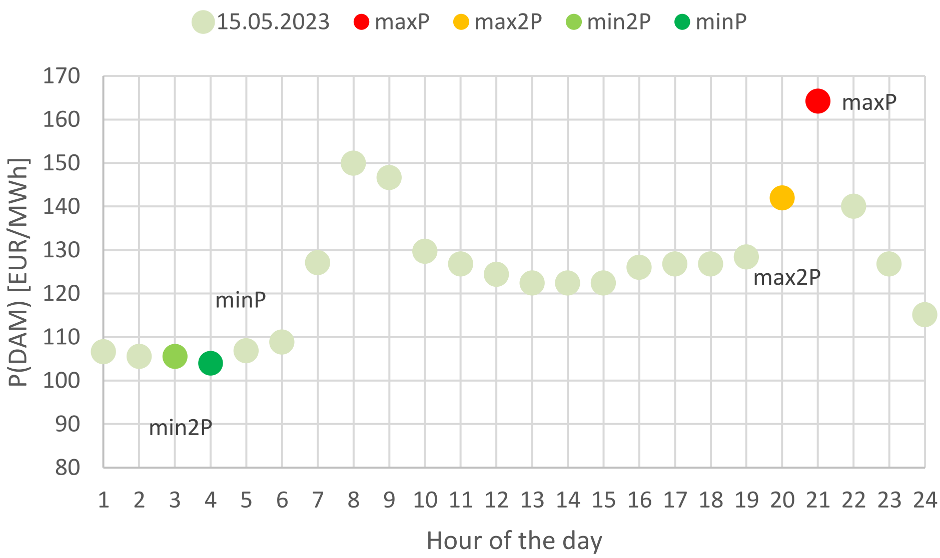


Fig. 5. The course of prices and proposal for selection of purchase and selling prices on DAM, 5/15/2023

Rys. 5. Przebieg cen i propozycja wybrania cen zakupu i sprzedaży na RDN, 15.05.2023

earlier, which eliminated the sales operation before 17:00. Therefore, the possibility of transactions at 8 and 9 must be rejected.

June 9, 2023 (Fig. 6) was chosen as the second day due to the very low price values. The average value is more than EUR 15/MWh lower than the average value for this market during the period under review. In addition, there is little variation in the course of prices. The difference between the highest and lowest value is EUR 27.76/MWh, which is less than 30% of the average energy price on that day. *MaxP* and *max2P* are not the highest values of the day. Their selection is dictated by the hourly constraint. In addition, the highest daily values, between 7:00 and 9:00 am, occur before the minimum value, which influences their rejection – the energy storage must first be charged (buying energy) and then discharged (selling energy).

On July 19 (Fig. 7), a scenario occurred where the market recorded the same energy price value for three hours. In this situation, the price in the second hour was chosen as *minP* and the first occurrence of this value was chosen as *min2P*. On this day, the highest prices of the three days considered were observed (in the figures above). The average price for this particular day is almost 20% higher than the calculated average for the entire considered period of 2023.

- Purchase and sale on the Intra-Day Market

On that day (Fig. 8), *maxP* and *max2P* are not the highest values in the intraday market. The highest prices were recorded at 8:00 and 9:00 am. The difference between the intraday market and the Day-Ahead Market may be due to a different demand for electricity during these hours than expected.

The October 9, 2023 (Fig. 9) is the first of the cases analyzed where the minimum prices do not occur side by side. They are spread over a period of 8 hours. In the case of the two maximum

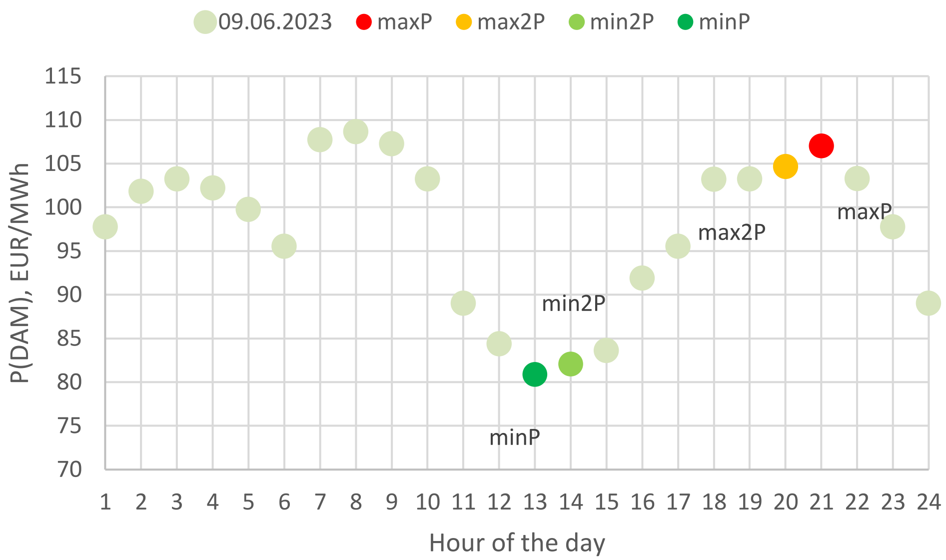


Fig. 6. The course of prices and proposal for selection of purchase and selling prices on DAM, 6/9/2023

Rys. 6. Przebieg cen i propozycja wybrania cen zakupu i sprzedaży na RDN, 9.06.2023

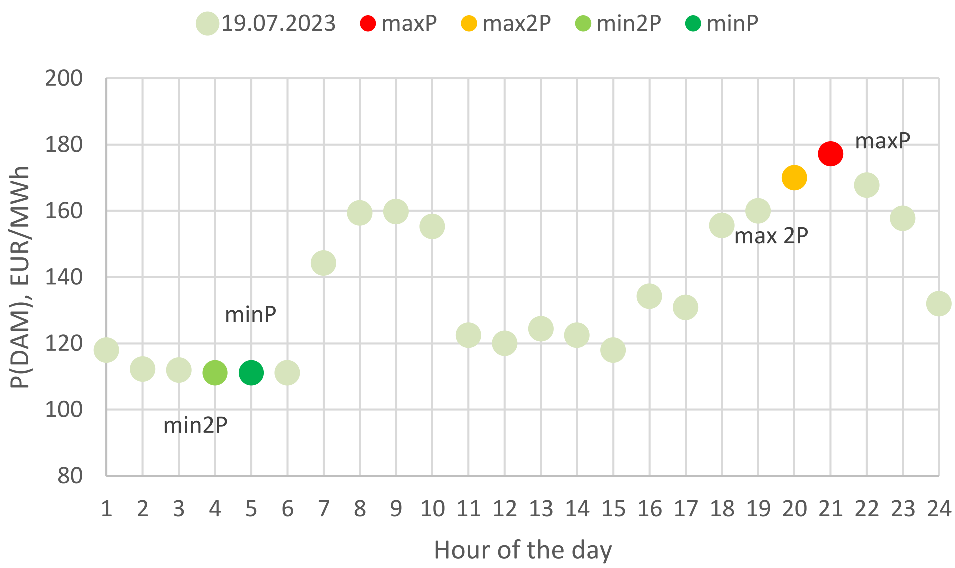


Fig. 7. The course of prices and proposal for selection of purchase and selling prices on DAM, 7/19/2023

Rys. 7. Przebieg cen i propozycja wybrania cen zakupu i sprzedaży na RDN, 19.07.2023

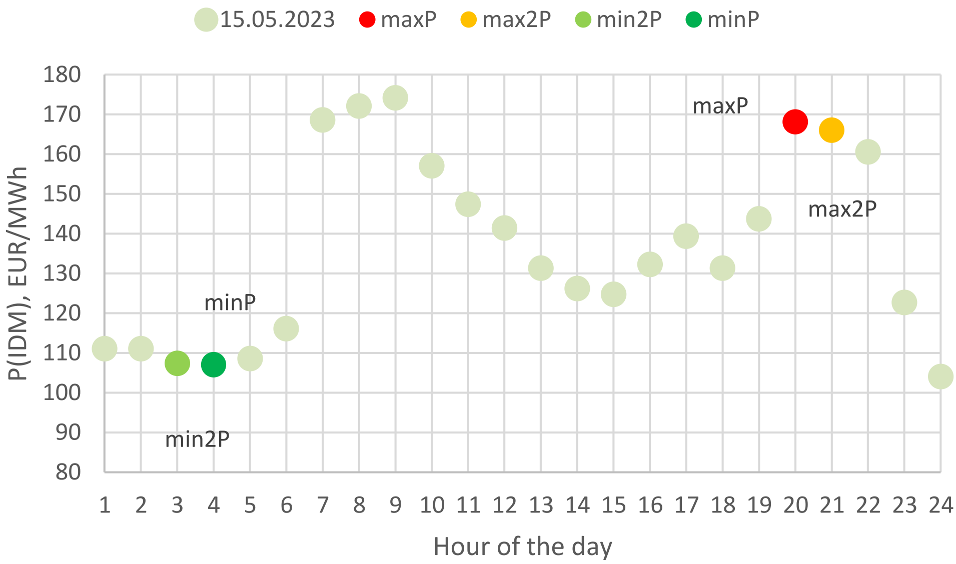


Fig. 8. The course of prices and proposal for selection of purchase and selling prices on IDM, 5/15/2023

Rys. 8. Przebieg cen i propozycja wybrania cen zakupu i sprzedaży na RDB, 15.05.2023

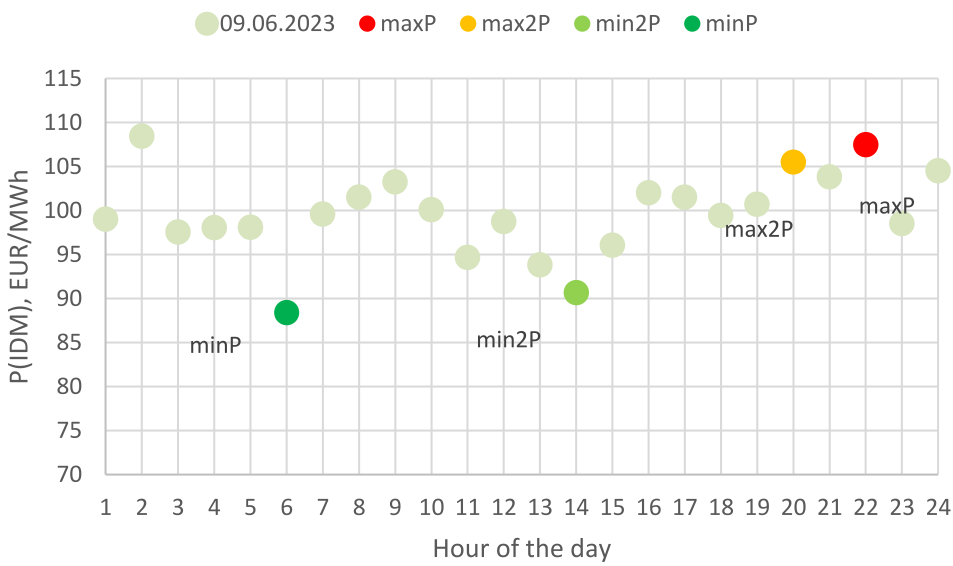


Fig. 9. The course of prices and proposal for selection of purchase and selling prices on IDM, 10/9/2023

Rys. 9. Przebieg cen i propozycja wybrania cen zakupu i sprzedaży na RDB 10.09.2023 prices, there has also been a separation between them. This affects the storage charging. The first recharge will occur at 6:00 am, and at 14:00, the warehouse will be recharged. A similar situation will occur when energy is sold. It will be split. Such operations will maximize profit. The analyzed day is another case where the hourly assumption influenced the non-selection of the actual highest price of that day (of 2:00 am) (Fig. 10).

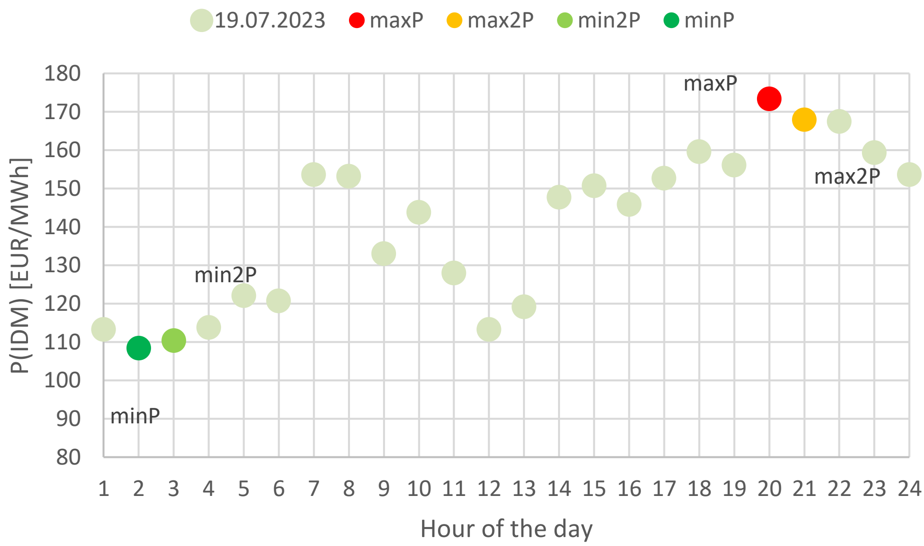


Fig. 10. The course of prices and proposal for selection of purchase and selling prices on IDM, 7/19/2023

Rys. 10. Przebieg cen i propozycja wybrania cen zakupu i sprzedaży na RDB, 19.07.2023

MinP and *maxP* represent the highest and lowest values. The price course of this day differs from the values in the following day's market. In this case, there are two visible peaks with maxima and two dips. Disregarding the hourly constraints, for maximum profits, two buying and selling operations could be conducted – buying at 2:00–3:00 and 12:00–13:00 and selling at 7:00–8:00 and 20:00–21:00. This would lead to profit maximization.

✦ DAM → IDM: Purchase on the Day-Ahead Market and sale on the Intra-Day Market

The previously considered days were again selected for analysis. This time, a scenario was considered where energy purchases take place on the Day-Ahead Market and sales take place on the Intraday Market. It was examined how splitting operations into two different markets would affect the daily profit DP (Fig. 11).

By performing operations on a single market, the absolute difference between the highest and lowest value was for DAM, IDM: EUR 60.22 and 61.10/MWh capacity. By splitting the purchase on DAM and the sale on IDM, the highest difference between the highest and the lowest price reached EUR 64.14/MWh capacity.

The calculated unit profit, with efficiency, for the different options was:

UP(DAM, 2023, 5/15) = EUR 32.68 /MWh capacity,

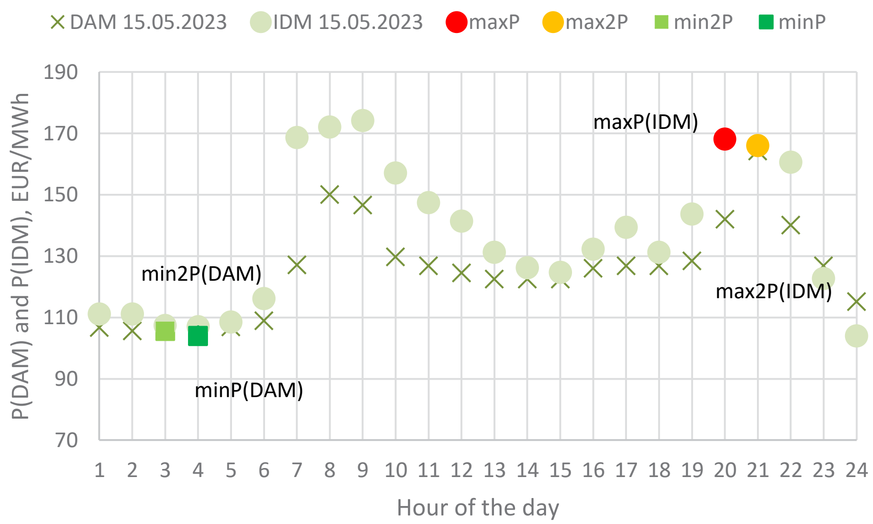


Fig. 11. The course of prices and proposal for selection of purchase on DAM and selling prices on IDM, 5/15/2023

Rys. 11. Przebieg cen i propozycja wybrania cen zakupu na RDN i cen sprzedaży na RDB, 15.05.2023

UP(IDM, 2023, 5/15) = EUR 43.85 /MWh capacity,

UP(DAM→IDM, 2023, 5/15) = EUR 46.66 /MWh capacity.

These values differ from the absolute value because they were calculated using the average of the two highest and two lowest prices of the day. The result was also affected by storage efficiency (Fig. 12).

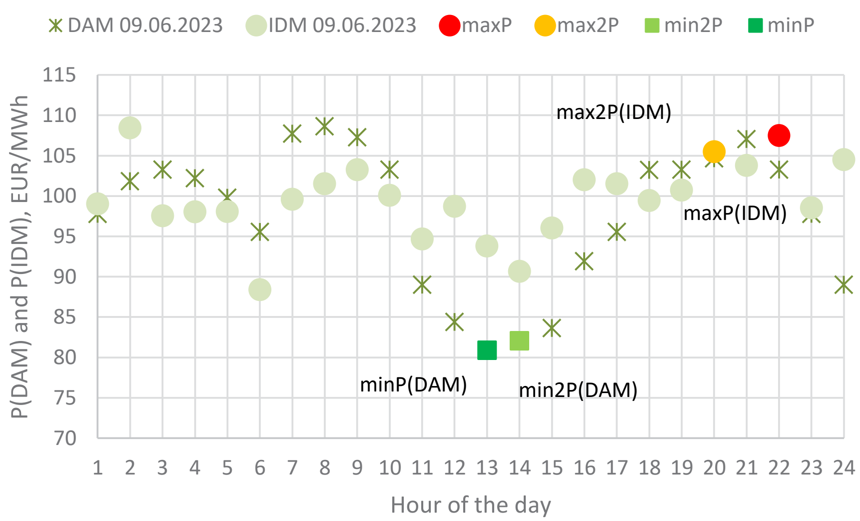


Fig. 12. The course of prices and proposal for selection of purchase on DAM and selling prices on IDM, 6/9/2023

Rys. 12. Przebieg cen i propozycja wybrania cen zakupu na RDN i cen sprzedaży na RDB, 9.06.2023

Buying energy on the day-ahead market resulted in a profit of around EUR 10 more than when buying and selling on the IDM. When efficiency is taken into account, the profit achieved is almost 10 times higher than that of the Day-Ahead Market.

For July 19 (Fig. 13), the differences between the price values for the two markets mainly occur between 8:00 am and 18:00. However, this does not affect the occurrence of the maximum and minimum and their values. The completion of the transactions on the different markets did not significantly affect the operating profit on that day.

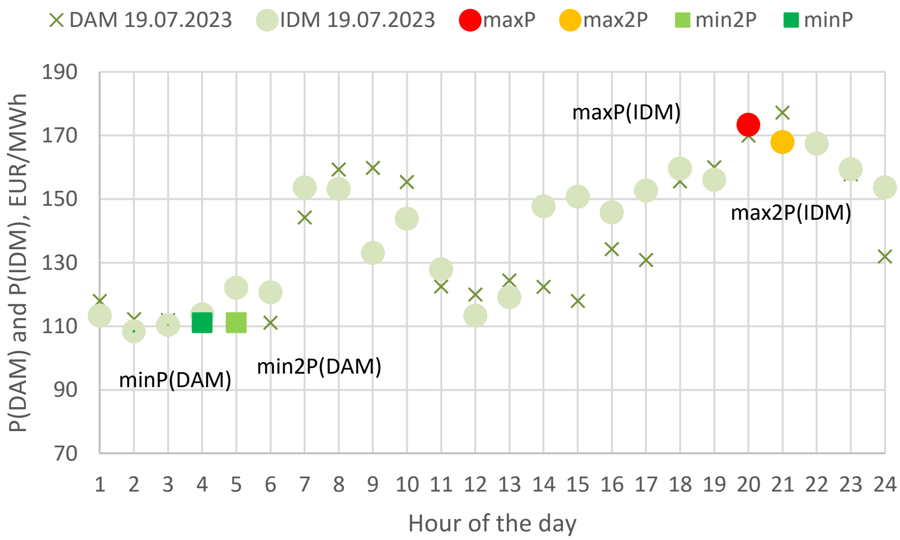


Fig. 13. The course of prices and proposal for selection of purchase on DAM and selling prices on IDM, 7/19/2023

Rys. 13. Przebieg cen i propozycja wybrania cen zakupu na RDN i cen sprzedaży na RDB, 19.07.2023

2.2. Results for 2021

✦ Purchase and sale on the Day-Ahead Market

For the analysis of 2021 (Fig. 14), dates that correspond to the previously selected days of 2023 were chosen. The course of prices in the older period is not as varied. Repetitiveness and predictability can be observed. The difference between the highest and lowest values is not as large, which affects the low return on energy storage. In that year, photovoltaic panels were less popular than today. There were fewer electricity suppliers and less demand for electricity, so there were not as many fluctuations in the market, which were largely caused by weather conditions.

The period profit *PP*(*ma*., *y*) was calculated for each market in the periods studied, and on this basis, the yearly profit *YP*(*ma*., *y*) was estimated for each case according to formulas (14–15). The results are presented in Table 1 and Table 2.

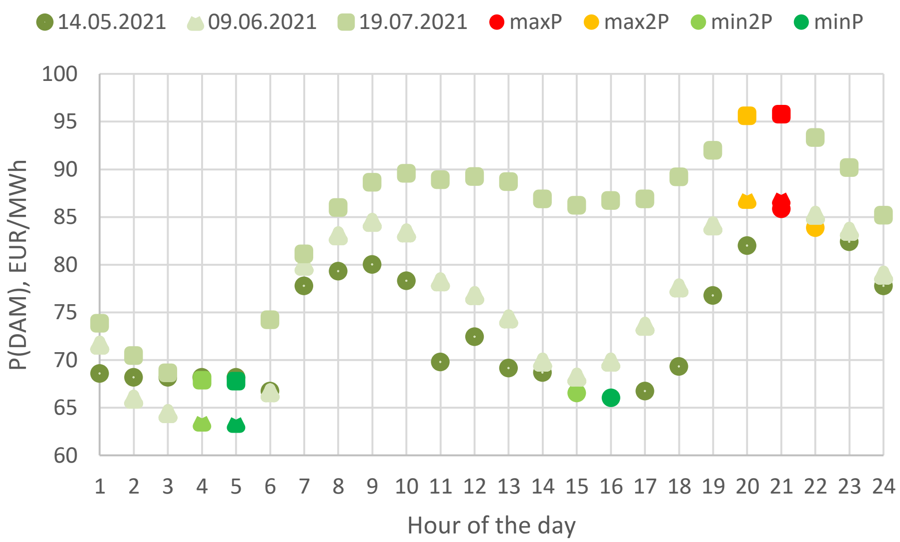


Fig. 14. The course of prices and proposal for selection of purchase and selling prices on IDM for three selected workdays

Rys. 14. Przebieg cen i propozycja wybrania cen zakupu i sprzedaży na RDB dla trzech wybranych dni

TABLE 1. Summary of period profits PP and yearly profits YP for individual markets

TABELA 1. Suma okresowych zysków PP i rocznych zysków YP dla pojedynczych rynków

	Profit [EUR/MWh capacity]							
	2023				2021			
ma.	IDM	IDM	DAM	DAM	IDM	IDM	DAM	DAM
η	100%	87%	100%	87%	100%	87%	100%	87%
PP (for 122 days)	7,449.60	5,895.01	7,489.29	5,884.94	3,566.69	2,517.29	2,769.59	1,639.28
YP (for year)	22,287.75	17,636.72	22,406.48	17,606.59	10,670.84	7,531.23	8,286.06	4,904.40

TABLE 2. Summary of period profits PP and yearly profits YP for mixed cases

TABELA 2. Suma okresowych zysków PP i rocznych zysków YP dla różnych przypadków

	Profit [EUR/MWh capacity]							
	2023				2021			
ma.	DAM→ IDM	DAM→ IDM	IDM→ DAM	IDM→ DAM	DAM→ IDM	DAM→ IDM	IDM→ DAM	IDM→ DAM
η	100%	87%	100%	87%	100%	87%	100%	87%
PP (for 122 days)	7,124.22	5,569.93	7,822.25	6,267.66	3,025.37	1,915.82	3,311.04	2,261.63
YP (for year)	21,314.27	16,664.14	23,402.64	18,751.61	9,051.31	5,731.75	9,905.97	6,766.36

Looking at the values given in the tables, the results seem promising. The year profit *YP* of EUR 5,000 /MWh capacity can be considered satisfactory. The maximum possible profit, taking efficiency into account, is *YP*(IDM→DAM, 2023) = EUR 18,751.61 /MWh capacity. This is already a relatively high value. However, it is not possible to determine whether the process is profitable without including an elementary analysis using the cost of the storage unit.

In order to test the viability of investing in an energy storage system to store the energy bought and sold in the markets analyzed, the approximate payback time for the purchase of the energy storage system was estimated based on the data presented above and the energy storage data (Commercial Battery Storage 2022). The results are shown in the graph below (Fig. 15).

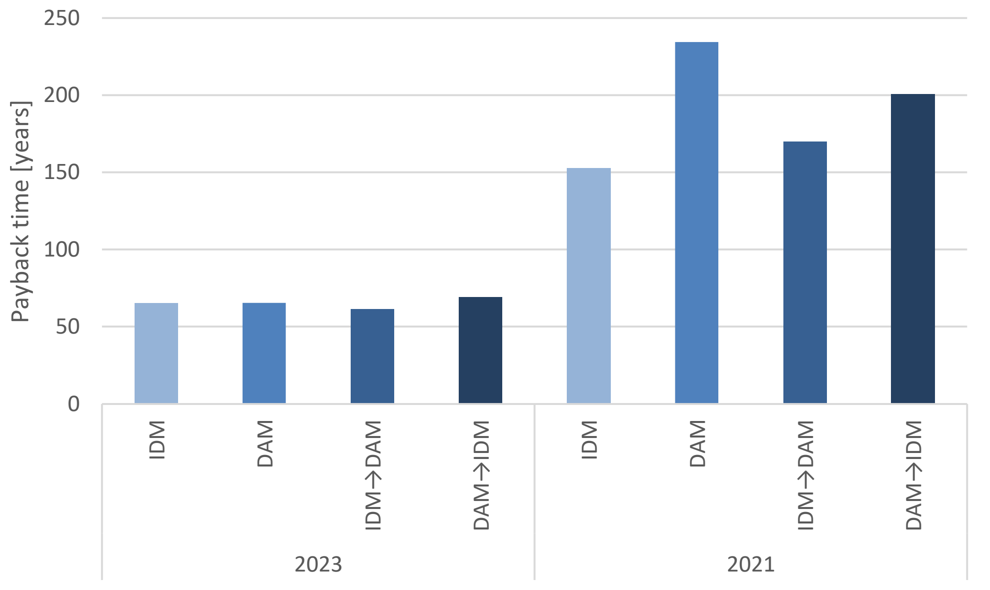


Fig. 15. Payback time for Energy storage system

Rys. 15. Czas zwrotu dla systemu magazynowania energii

The shortest payback period was observed for buying electricity on IDM and selling on DAM. However, this time is very long at just over 61 years. Compared to the most unfavorable scenario, *YP*(DAM, 2021) compares well – the payback time is reduced by more than 3.5 times. However, when the lifetime of storage in the form of lithium-ion batteries is taken into account, the time is significantly too long. The graphical representation shows the price differences between the IDM and DAM markets – the most favorable and worst case in 2021. There is a difference of more than 80 years in the payback period. For 2023, the values are comparable. There are no such drastic differences – the biggest difference is less than 8 years.

Summary and conclusion

Due to the increasing ratio of renewable energy sources in electricity generation in Poland, the need for energy storage has become crucial. Therefore, the problem was analyzed from the point of view of energy storage purchased on the POLPX electricity markets, searching for the most economically beneficial scenarios.

As calculated, the most profitable case after taking efficiency into account was the case of purchase at IDM and sale at DAM in 2023. The profit was *YP*(IDM→DAM, 2023) = EUR 18,751.61 /MWh capacity. In comparison, the highest value for 2021 was obtained for the case of sale and purchase on IDM, with a profit of *YP*(IDM, 2021) = EUR 7,531.23 /MWh capacity, which is 40% of the highest profit of 2023. The average price of MWh capacity on the IDM increases by 59% in 2023 compared to 2021. In contrast, the profit, taking efficiency into account, increased by 134%. In DAM, the average price experienced a similar increase of 60% relative to 2021. However, the profit gained increased by almost 260%, which is due to the higher absolute values between the highest and lowest prices during the day.

In addition, as the above work shows, the use of energy storage only for economic purposes is not cost-effective. This is due to the payback period being too long, which significantly exceeds the lifetime of the selected energy storage. The considerable alteration in both profit and payback time of storage within two years highlights the potential for further improvements in this field, as energy storage will be crucial for the development of RES.

Although the analysis indicates that the measures presented are not cost-effective, the potential for further research and development of the work can be seen. It is proposed that an additional constraint that will relate to the timing of purchases and sales be investigated so that the two lowest (and two highest) prices are in consecutive hours. This will eliminate the process of topping up the warehouse. The second aspect that can be explored is to maximize profit as much as possible by having two charging and discharging cycles per day. This can be achieved due to the increasing occurrence of price peaks in the morning and evening and dips at night and midday. This situation is being driven, in particular, by the contribution of solar power and the further rise in popularity of photovoltaic panels.

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Ocena opłacalności ekonomicznej wykorzystania magazynów energii w obliczu wzrostu produkcji energii odnawialnej

Streszczenie

Magazynowanie energii jest coraz ważniejszym aspektem sektora energetycznego w Polsce ze względu na rosnącą popularność odnawialnych źródeł energii. Jego jednym z głównych celów jest wspieranie wykorzystania energii odnawialnej w miksie energetycznym kraju. W prezentowanym artykule dokonano analizy potencjału ekonomicznego zakupu i sprzedaży energii elektrycznej na Rynku Dnia Bieżącego i Rynku Dnia Następnego Towarowej Giełdy Energii SA (Polski Rynek Energii: TGE) w zakresie magazynowania energii. W czterech scenariuszach energię kupowano i sprzedawano na RDN/IDM lub kupowano na jednym rynku i sprzedawano na drugim, aby określić najkorzystniejszy przypadek. Badano dwa czteromiesięczne okresy w latach 2021 i 2023. Przeprowadzono analizę magazynu litowo-jonowego, który posiada dwugodzinny cykl ładowania w celu magazynowania energii. Zaproponowano metodologię identyfikacji dwóch najwyższych i dwóch najniższych cen energii w celu nałożenia ograniczeń na czas zakupu i sprzedaży. Analizie poddano także porę dnia, w której te ceny występowały. Obliczono roczne i okresowe zyski, które można uzyskać z zakupu i sprzedaży zmagazynowanej energii. Przeprowadzone obliczenia i analizy umożliwiły porównania międzyrynkowe. Obliczono czas zwrotu magazynowania energii oraz zbadano opłacalność inwestycji. W ostatniej części przedstawiono wnioski oraz możliwości i sugestie dalszych badań w tym obszarze.

Jak obliczono, najbardziej opłacalnym przypadkiem po uwzględnieniu efektywności ekonomicznej był zakup na RDN i sprzedaż na RDN w części 2023 roku: 18 751,61 [EUR/MWh mocy]. Dla porównania, najwyższą wartość za rok 2021 uzyskano w przypadku sprzedaży i zakupu na IDM, z zyskiem na poziomie 7531,23 [EUR/MWh mocy].

SŁOWA KLUCZOWE: odnawialna energia, magazynowanie energii, ekonomiczne obliczenia, rynek dnia bieżącego, rynek dnia następnego