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ORIGINAL RESEARCH ARTICLE

Analysis of the selected business models for energy storage in the Polish Power System

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ABSTRACT

Along with the changes taking place in the power system, including the increase in share of RES generation and the increasing importance of prosumers, the importance of energy storages is increasing, which, with a further increase in share of nondeterministic generation, will become not only necessary, but also indispensable to ensure the stability in the power system. The amendment to the Energy Law and the Act on renewable energy sources of 2021 creates new opportunities in the area of energy storage, which may become a pillar of the energy transformation and the whole system. In order to make what is technically feasible, to be also feasible from the business perspective, it is necessary to define business models based on newly defined principles. The article presents the results of the financial analysis performed for six scenarios based on two types of business models of using energy storage.

Keywords: energy storage; renewable energy sources; price arbitrage; financial modeling

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1. Introduction

In this article, we present the results of the financial analysis of selected business models, which goal was to verify possibility and profitability of energy storage investment in the Polish Power System (PPS). The purpose of the analysis was to determine the profitability or unprofitability of investing capital under an ex ante account in investment projects assuming different business models for the use of energy storage. Our analysis was made for energy storages with 1 MW of installed power, 4 MWh capacity and two different technologies for storing energy (LI-ion and acid-Pb).

The first part of the article describes the currently used storage technologies and the implementation of key R&D projects in Poland and around the world, with an indication of the business models that are considered when using this technology. In the next part, the adopted assumptions for the economic model are presented, its structure is discussed and the scenarios for the use of energy storage are described. At the end, the results were discussed, conclusions were described and recommendations for further actions were indicated.

The analysis of the literature carried out by the authors showed that research on the economic efficiency of the use of storage facilities for stabilization of selected technologies of electricity generation from unstable sources is common[1–5] or analysis of the costs of purchasing energy storage[3,4,6–8]. Publications concerning the description of various storage technologies, their division and classification by design are also common[2,9–15]. In the final part of Aneke and Wang[11] some of the challenges hindering the commercial deployment of energy storage technologies are highlighted. We managed to find several foreign publications regarding the economic assessment of alternative business models for storing energy in a given technology, e.g., compressed air[16]. In Baumgarte et al.[17] it is stated that the rapid growth of intermittent renewable power generation makes it necessary to identify investment opportunities in energy storage and establishment of their profitability indispensable. A conceptual framework is presented to characterize energy storage business models and systematically differentiate investment opportunities. We then use this framework to examine which storage technologies can perform the identified business models. The analysis shows that a set of commercially available technologies can serve all identified business models. In López-Grajales et al.[18], the authors propose an economic and financial model to evaluate the use of electricity storage in the power grid for various business cases and scenarios. The models focus on self-generation photovoltaic battery storage, primary frequency control storage, and secondary frequency control storage. The scenarios include real economy models that include tariff formulas for the remuneration of distribution companies and the regulations applicable to renewable energies in Colombia. Energy storage in China has entered the initial commercialization phase from the demonstration project stage. Therefore, in order to realize the commercialization of energy storage on a large scale, it was necessary to analyze the energy storage business model. It provides readers with an overview of energy storage that will contribute to the future development of business models for the profitable application of this technology[19]. Economic and financial appraisal of novel large-scale energy storage technologies was performed in Lai and Locatelli[20]. This paper presents and applies a state-of-the-art model to compare the economics and financial merits for GIES (Generation Integrated Energy Storage system) (with pumped-heat energy storage) and non-GIES (with a Lithium-ion battery) systems coupled with wind generation in the United Kingdom. The Monte Carlo method was used to perform the analysis. However, we did not find any analyzes of the profitability of using large-scale energy storage in various business models for National Power System (NPS) in Poland. The development of energy storage in our country is accelerating, which has extensively promoted the development of energy storage technology. Even though several reviews of energy storage technologies have been published, there are still some gaps that need to be filled, including: a) the development of energy storage in Poland; b) role of energy storage in different application scenarios of the power system; c) analysis and discussion on the business model of energy storage in Poland. There was not specified any economically profitable use case for energy storage in NPS. Energy storage properties, such as fast reaction time, ability of stable operation almost with no technical minimum, provide wide range of possibilities of its usage—the boundaries are set by economy and laws of physics—operating costs of energy storage and its capacity.

The main barrier for largescale usage of energy storages are high construction costs. Apart from that, the economic efficiency of energy storage is determined by e.g., daily number of full charge/discharge cycles, efficiency of storage technology and its decrease over time, overall lifetime expectancy depending on storage technology. Energy companies around the world (also in Poland) have launched research projects to test the use of energy storage to ensure grid stability overloaded by wind farms and photovoltaics. Today, warehouses have a new role in the market, focused on the widely interpreted issue of managing peak power consumption and electricity savings in general. This is due to limitations in the access to energy resources, disruption of supply chains, and thus a drastic increase in energy prices, and at the same time the deficit of power and energy in the European continent's network. In our study, we take into account the possibility of energy storage participation in RES auctions and in the capacity market. It is also almost certain that the first priority for the use of energy storage will be in the PPS-balancing the system in the conditions of high generation variability, the management of storage facilities in the event of a threat to the balance (in a non-market manner) becomes particularly critical.

Because of current state of the NPS and future challenges, including limited access to fossil energy resources, increasing share of RES generation in the total generation as a result of the formation of energy cooperatives and energy clusters as well as popularization of electromobility and the resulting need to obtain flexibility as a service and to ensure stability of generation, energy storage is not only needed, but even indispensable to ensure continuous system operation.

Changes in the energy law have removed barriers to the development of electricity storage in Poland, but so far it has not been possible to create conditions for their development. Meanwhile, energy storage is an important element of the functioning of the NPS, which during the transformation period will ensure the efficiency of grid use and the stability of its operation in the period of decarbonization. They can be used both on the balancing market (peak generation) and constitute a source of reserve. Energy storage can be a substitute for grid expansion, and they can certainly help in avoid many modernization investments. They improve the flexibility of the system operation, support the construction of low-emission energy, and increase the possibilities of using generation from renewable energy sources. They allow the transition from a central generation system to a distributed one, located closer to the end user. Thus, the operating cost of the system is reduced due to shorter transmission distances and lower losses. They increase the NPS work safety, supporting the process of balancing the demand and supply, thanks to the improvement of power quality and grid reliability, and in emergency situations they constitute a backup source of electricity, supplying the most critical devices. In the present conditions of a threat of energy and capacity deficit, energy storage facilities can become a reserve source in the event of a threat to the balance because storage facilities have the ability to compensate for unstable RES operation. This allows for stable operation of the system without the need for grid investments, in particular in the medium voltage network. Large storage installations planned to be built in DSO networks are often used to support the reliability of the local grid. The increase in the share of RES in electricity generation causes an increased demand for this technology. Energy storage facilities ensure flexible operation of power system and increase the system capacity to connect additional RES installations. This does not mean that there is no need to expand and modernize the transmission and distribution networks, but it reduces the risk of overinvesting in the network and the risk of stranded costs in the next several years. Thanks to the battery and pumped-hydro (According to PEP, pumped-hydro facilities may be treated as energy storages) energy storages, in the future it may be possible to balance the demand for electricity with energy produced from wind and photovoltaic farms. Large-scale energy storages are only part of the solution, also smaller local energy storages are needed to meet PEP2040 target that prosumers will become the second pillar on which the Polish energy transformation will be based. When there is a high penetration of PV installations in the grid of the NPS, the so-called duck curve phenomenon can be observed, consisting in the fact that there is a deep difference in the demand for electricity and the amount of solar energy available during the day, because when the sun is shining, solar energy floods the market, and then drops when electricity demand peaks in the evening. For the effective operation of RES infrastructure in Poland, it is necessary to create distributed network of energy storage facilities, which will allow for the accumulation of larger amounts of green energy and its utilization at times of peak energy demand, i.e., in the morning, afternoon and evening. The time of peak generation of PV installations at noon, does not match with the peaks of energy demand. Moreover, the operation of PV installation in winter does not produce enough electricity to cover building's demand, but in the summer raises overgeneration issues. In addition, solar and wind installations, because of its stochastic nature and high dependency on the weather conditions, can cause significant fluctuations in the energy supply and, in extreme cases, cause complete break of energy supply. In order to reduce negative impact of RES on the grid, the stabilization measures should be made as close as possible to those energy sources and be adjusted to local grid conditions.

1.1. Legal environment of energy storage in Poland—The current status, and the system coming into force on the 2 July 2021 r.

Until recently, energy storing was not tackled by Polish law, the "energy storage" term has been defined in the energy law in 2018, despite the fact that for years we have been using the method of storing huge amounts of energy on a large scale in pumped storage power plants. The main purpose and advantage of these power plants is to balance the power balance in the power system. These power plants also fulfill the task of frequency regulation due to the speed of response to sudden disturbances in the demand and generation balance. Therefore, with a rapid increase in the share of wind and solar power plants with a very variable generation, pumped storage power plants will start to function as energy storage, which will significantly improve the economics of the RES segment. Energy storage expansion in Poland was not supported by the law, but last amendments to the energy law, which came into force on 2 July 2021, may become a game changer[21]. The amendment allows the investment process to be carried out, by straightforward legal status, including schematic description of the investment process in energy storage, indicates the standards and uniform conditions for its connection and the principles of its cooperation with the grid. The energy storage technology, covered by the amendment, may become a pillar of the energy transformation and the whole power system.

As for now, no business models for energy storages have been defined. Those models are essential to make feasible from the business point what is permissible from the technical and legal point of view. In the new regulatory order, investment in energy storage may constitute a justified cost for system operators, which facilitates the use this technology for the purpose of ensuring system security. The RES law amendment[22] allows for auctions to be carried out for hybrid installations which include energy storages. Solutions promoting the symbiosis of renewable energy installations and energy storages—also connected in different network nodes, should release network congestions and thus provide benefits from such cooperation for the functioning of power system. In 2021, thanks to the amendment of the law, for the first time, an auction allowed for the sale of 394 GWh of energy generated in hybrid installations with an installed capacity of no more than 1 MW, worth PLN 242 million. Pursuant to the new definition, the hybrid installation is to be obligatorily equipped with an energy storage, and its installed capacity should be at least 60%, i.e., 5256 hours. As a result of conducting the auction in accordance with the volumes specified in the draft regulation, 5 MW may be generated in hybrid RES installations with an installed capacity of no more than 1 MW and 15 MW in installations with a capacity higher than 1 MW[23].

Amendments to the law act, as well as other regulations, including the capacity market act[24], will affect the way in which business models for energy storages would shape. The strategy Polish Energy Policy (PEP 2040)[25] places great hopes on the development of distributed sources, which, thanks to the successive editions of the My Electricity program, contribute to an increasing share of distributed generation in the energy mix. However, for further development, the assumptions have to be modified in order to support hybrid installations equipped with an energy storage system.

1.2. Research background

1.2.1. Energy storing technologies

The Energy Storage Systems (ESSs) classified into various technologies as a function of the energy storage form and the main relevant technical parameters. In Georgious et al.[2] the most common classifications are presented, summarized, and compared according to their characteristics. However, AL Shaqsi et al.[9] may contribute to guide the decision-makers and the practitioners if they want to select the most recent and innovative devices and systems of energy storage for their grids. The characteristics, advantages, limitations, costs, and environmental considerations have been compared with the help of tables and demonstrations to ease their final decision and managing the emerging issues.

The most popular technology for storing energy is pumped hydroelectric energy storages (PHES). United States, Norway or Japan are the countries that used their elevated geographic features to create reservoirs, which are filled with electrically powered pumps. Currently also electro-chemical technologies are being developed, including battery electric storage systems (BESS). E.g., PGE group, in its strategy from October 2020, announced an energy storage programme, which goal is to build at least 800 MW in new energy storages in order to increase possibility of connecting new RES to the grid and improve reliability of the grid[26]. Pilot project on the Żar mountain, with 0.5 MW of installed power and 750 kWh capacity will be used to provide ancillary services for grid stability and regulation in medium voltage distribution network[8]. The biggest BESS in Poland, with 6 MW of installed power and 27 MWh capacity passed the initial testing phase at the beginning of April 2021 and has been already commissioned. It's a part of the Polish-Japanese project, realized from 2017 by PSE, Energa and Hitachi, in which a Special Protection Scheme (SPS) system with correspondent BESS on the Bystra wind farm is being developed. Energy storage on the Bystra wind farm has a mixed technology—1 MW with Li-ion batteries and 5 MW with lead-acid batteries[8]. The goal of whole installation is to improve the controllability of NPS in high wind generation situations. This energy storage will ultimately work with SPS system, which together will have ability to:

- provide frequency restoration reserves;
- provide replacement reserves;
- smooth out the wind farm power output fluctuations;
- take part in price arbitrage.

Currently, next to the large storage facilities in the form of pumped-hydro power plants, lithium-ion (Li-ion) technologies are most common. LF-P (lithium-iron-phosphate) battery electric storages offer lower energy densities than Li-ion cobalt-based cells, but are up to 30% cheaper, have longer lifetime, because they can withstand more charge-discharge cycles and at the same time are safer[27]. On the other hand, flow batteries have a lifetime of 15 thousand cycles[27], offer independent scaling of the storage capacity and its power, use non-flammable, recyclable electrolyte and their full capacity can be used (Li-ion storages allow to effectively use 80% of their capacity, because discharging them below 10% and charging over 90% significantly reduces battery lifetime). Quite promising is the power to gas (P2G) technology, including the use of green hydrogen for storing and use of gas in the electric power industry, but it has only 30% conversion efficiency[27]. However, hydrogen may still become an important competitive and technological advantage of Europe. Among others, CIGRE[28], as part of the work of the C1 committee, deals with the development of recommendations for technological solutions in order to ensure compliance with the network code and enabling a market approach to large-scale flexibility services provided by electrolysers. It is also possible to use a supercapacitor as an energy storage, which allows for storing energy with a higher density and can work with higher power values. This type of device is durable and has small loses of efficiency over time. The disadvantages of this technology include low energy density (maximum values are up to 25 Wh/kg, compared to Pb: 70 Wh/kg, Li: 100 Wh/kg, NiMH: 90 Wh/kg) and low permissible operating voltage (2–3 V).

1.2.2. Energy storage as an essential supplement to PV installation

Poland is one of the leaders in Europe in recent years in photovoltaics expansion. In the year 2020 photovoltaic installations with a total capacity of 2.2 GW were installed in our country—two times more than in 2019. At the end of 2020, the total installed capacity of photovoltaic panels in Poland was 4 GW[29]. According to the IEO forecasts from that year, by the end of year 2022, installed capacity should increase by another 2.8 GW. Meanwhile, at the end of July 2022, the installed capacity of photovoltaics in Poland was as much as 10.6 GW. This is almost 87 percent more than in 2021, when 5.6 GW was recorded. The forecasts were significantly wrong. This difference is the result of initially changes in the co-financing of the purchase of installations and settlements of electricity production for prosumers, and in the second step, the turbulence in the energy market related to the uncertainty of energy supply and the forced search for sources of savings due to the drastic increase in electricity consumption prices. It is worth to emphasize the important role of energy storage in relation to the new rules for the settlement of prosumers. In order for energy storage to become the object of investment, two issues must be taken into account: appropriate subsidies, tax allowances and loans promoting the cooperation of renewable energy sources with energy storage and also well-defined legal regulations. So far, the development of the photovoltaic market in Poland was driven by support programs[30]. Co-financing of the purchase and installation of photovoltaic installations can be obtained under programs like: Mój Prąd, Czyste Powietrze, Energia Plus, StopSmog or Agroenergia[31]. Properly prepared legal framework for energy storage would allow for full use of the functionality of PV systems, which in combination with the energy storage would no longer be a source of unstable generation, but a flexible element of the system which supports its stable operation. Meanwhile, most installations are operating in the on-grid mode, which means that the PV micro-installation always works in conjunction with the power grid. On-grid means full integration, but also complete dependence of the installation on the operation of the distribution grid. The prosumer produces the most when its demand is the lowest, and at the same time pushes excess energy into the grid, treating it as his “accumulator”. In practice, the self-consumption rate of electricity produced in single-family houses is often very low, as it is estimated that up to ¾ of the electricity produced goes to the distribution grid[32]. The prosumer receives a subsidy for the installation, while the operating costs of his micro-installations are charged to the distribution system, thus they will be charged to the other end-users in their electricity bills. Moreover, during the peak period, the prosumer, as a privileged unit, obtains the electricity he needs on more attractive terms than the rest of end-users. More effective solution would be a hybrid system, which is a type of installation that transfers to the grid only excess energy, exceeding the capacity of the local storage. It is not an ideal solution because a hybrid system, similarly to PV systems in the on-grid option, gives back and receives electricity from the common grid at any time. The advantage of this system is the ability to use electricity from the distribution network as well as stored in local batteries (energy storage). In case of a power system failure and power outage, or user decision, the hybrid system can be switched to use electricity from its own energy storage. Co-financing should be adopted at a level that will be an impulse for a rational, well-thought-out, economically justified investment by a prosumer. In connection with the changes to the RES Act implemented in 2022, which reformulated the settlements for prosumers, we can expect that systems based on self-consumption of energy and storing excess amounts without burdening the energy system during the peak of energy consumption period will be rewarded. Energy storages are largely needed to stabilize the grid operation. The low and medium voltage grid infrastructure is outdated in many places, as it has not been modernized for years and is not prepared to connect a large number of photovoltaic micro-installations in one place. The transformers, which were installed several decades ago, were supposed to fulfill a different function than the one for which they are currently needed, i.e., to output power from micro-installations. We can therefore expect that at some point the low voltage grid will be saturated and it will not be possible to connect more photovoltaic installations in a given location without taking into account the energy storage.

2. Methodology

2.1. Available solutions for the use of energy storage in the context of the potential provision of ancillary services

As part of the study, possible business models for electricity storage were analyzed, including:

- Price arbitrage, i.e., obtaining a profit through buying energy during off-peak when it is the cheapest and selling it during peak demand;

- Commercial storage service for PV installations (the virtual/central storage service can be very attractive in the event of a change in legislation towards regulation of the time of that PV is allowed to inject energy into the grid without penalties for feeding energy into the grid during off-peak periods);
- Participation in the capacity market auction and the provision of capacity services.

No economic analyzes were carried out for the use of energy storage in business models assuming that the storage:

- Provides an emergency power source—UPS. The energy storage used in the Polish village of Rzepedź, located in the Podkarpackie Province, allows to provide emergency power to consumers connected to the Rzepedź substation for about 2 h. This allows the operating services to change grid topology and restore the power supply[33].
- Is an alternative to grid investments by reducing the volume of power flows on critical lines during peak hours. Thanks to the use of energy storage in Rzepedź and Cisna in cooperation with the Bukowsko Wind Farm and the Myczkowce Water Power Plant, PGE significantly improved the reliability of power supply for the entire Bieszczady area, and postponed the construction of the 110 kV line by about 15–20 years[33].
- Supports the grid during peak hours and is charging when there is lower energy demand. This primarily leads to better use of network assets, e.g., it may reduce number of power plant start-ups and shut-downs. In some cases, the cost reduction is compensated by the purchase cost of the installation itself.
- Provides ancillary services, including: frequency regulation, load following (15 min to 24 h), voltage regulation, black start, spinning reserve (compensating for unforeseen fluctuations in demand and supply).
- Influences the reduction of capital expenditures (CAPEX) by avoiding over-dimensioning of the system. In oversupply situations, the hybrid system can store surplus energy and become additional power source when demand levels will rise.
- Influences the reduction of operating costs (OPEX). Hybrid systems can increase the efficiency of the power system, achieve better quality of power supply and avoid power outages caused by grid instability. Fuel and maintenance costs are lower than in conventional power generating systems.

2.2. CRO in the model

Despite the fact that the balancing market is not a place of price arbitrage, the model adopted balancing energy prices instead of stock prices due to their greater volatility. In addition, the model does not include distribution fees for energy consumption from the grid (Currently, pumped storage plants and energy storage installations are charged for all consumed energy. According to the regulations being implemented, under the Energy Law in Poland, the fee will be multiplied by a factor equal to storage losses (100%—storage efficiency)). **Table 1** presents the analysis of the data clearing price of the deviation in the electricity balancing market (CRO) from 2021 in the period from January to June in order to assess their volatility and, at the same time, their usefulness for the implementation of the investment projection. It is worth noting that the higher the price differentiation occurs in individual hours of the day, the more favorable the model will be. In 2021, moderate price volatility was observed. The only exceptions are related to the unavailability of blocks or failures of power stations. The highest average difference per day is about 300 PLN. The highest differences were recorded in May 2021. However, the maximum deviations in the model are treated as anomalies and we are looking for certain repeatable patterns. In the projection we assume the probable and most realistic level not exceeding the average values.

Table 1. Balancing energy price analysis for the first half of year 2021—own calculation based on PSE S.A. data.

	January	**February**	**March**	**April**	**May**	**June**	**Median**	**Average**
Daily max (average)	317.311	330.8771	353.8603	348.4877	894.6123	471.38	351.174	452.7543
Daily min (average)	169.7997	136.9104	154.2258	156.446	27.93452	266.39	155.3359	151.9518
Difference (average)	147.5113	193.9668	199.6345	192.0417	866.6777	204.98	196.8007	300.8025
Min difference	12.86	115.69	101.24	76.49	0	58.64	67.565	60.82
Max difference	327.12	492.46	304.64	322.5	13,398.29	1155.75	409.79	2666.793
Min/h (average)	112.6779	75.27958	120.4904	0	261.6992	264.52	116.5842	139.111
Max/h (average)	354.9846	398.9671	367.0342	0	577.7704	418.64	383.0006	352.8994
Max difference/h	410	690.61	314.66	0	401.39	1076.37	405.695	482.1717

2.3. Assumptions to the economic model of the energy storage usage—Use cases

The expected rate of return has been estimated as WACC, which indicates the overall required financial return on the company as a whole. The rate defined in this way is used to determine the possibility of economic expansion. This is the appropriate discount rate to use in discounting cash flows with a similar risk to that accepted in a given company. WACC estimated at 6.27% (**Table 2)**. WACC was calculated according to the formula:

$$WACC = [(I_D \times (1 - T) \times D) + (r_e \times E)]/(D + E)$$

I_D—debt interest rate [%],

T—income tax rate [%],

D—foreign capital value (credit) [PLN]

E—equity value [PLN]

r_e—cost of equity capital [PLN]

- Income tax was adopted as 19% for each year (This is the tax level for entrepreneurs in 2021. The calculations assume that the tax will remain constant in the analyzed period).

Table 2. Sensitivity analysis of changes in parameters influencing the WACC value.

WACC	**6.27 PLN**	**6.03 PLN**	**6.52 PLN**	**6.84 PLN**	**5.71 PLN**	**6.57 PLN**	**5.97 PLN**
Capital expenditure	1,858,550 PLN	1,858,550 PLN	1,858,550 PLN	1,858,550 PLN	1,858,550 PLN	1,858,550 PLN	1,858,550 PLN
Debt interest rate ID [%]	6.83%	6.83%	6.83%	7.83%	5.83%	6.83%	6.83%
Foreign capital value **(**loan**)** D **[**PLN**]**	1,300,985 PLN	1,486,840 PLN	1,115,130 PLN	1,300,985 PLN	1,300,985 PLN	1,300,985 PLN	1,300,985 PLN
Equity value E [PLN]	557,565 PLN	371,710 PLN	743,420 PLN	557,565 PLN	557,565 PLN	557,565 PLN	557,565 PLN
Cost of equity capital rE [PLN]	8%	8%	8%	8%	8%	9%	7%
Parameter subject to sensitivity analysis	-	D/E + 10%	D/E − 10%	iD + 1%	iD − 1%	rE + 1%	rE − 1%

Calculating the WACC value is a challenge in itself, not least because of the subjectivity of data selection and the selection of their sources. Due to the high sensitivity of WACC to the variability of input data, a sensitivity analysis was performed to show how our WACC will change depending on fluctuations in parameters such as: D/E, ID, rE. The results are included in **Table 2**. When we change the proportion in terms of the loan taken and own contribution, the ratio of D to E changes. In the case of an increase in the value of equity, the WACC value increases, which means that the profitability of our investment is more difficult to obtain. It also has a big impact on the WACC value and thus the profitability of the entire model. The lower the interest rate on the debt, the lower our WACC, and therefore the higher the profitability of the projection. In order to take into account the impact of the analyzed project/investment on other parts of the created system (business/cluster/enterprise/association), in the calculations we take into account the residual value at two levels:

- assets acquired or generated as part of the project,
- working capital, including receivables, inventories and liabilities.

WACC as indicator is in most cases relative, which means that its interpretation requires comparison with other data or information about the investment project. It is therefore worth comparing it with another financial indicator—the so-called internal rate of return (IRR). In simple terms, this indicator determines the rate of return on investment in a given period. Therefore, it is important that when assessing the attractiveness of investment projects, the IRR is higher than the WACC. This means that the return on investment will be greater than the weighted average cost of capital that should be invested in the project.

The following assumptions are used as a baseline data for all business models (**Tables 3** and **4**):

- 20 year loan period, equal to the economic life of the project,
- 6.83% interest rate (The average fixed loan interest rate at the time of model execution, (**Table 1**—parameters for the preparation of debt financing projection)),
- 12 months settlement period,
- the beginning of the calculation period was assumed for May 2021,
- the end of the calculation period is April 2041,
- the financing structure assumes the distribution of 30% equity and 70% external capital (investment loan);
- the cost of equity, i.e., the minimum expected rate of return on equity, was adopted at the level of 8%.

This is the rate of return required by business owners based on the rate of return on alternative projects with similar risks. It is the minimum rate of income that will make the investor undertake the implementation of a given investment project or decide that it is worth implementing.

Table 3. Baseline data used to make financial projections.

Baseline data	
Beginning of the operating period	01.05.2021
Completion of the project implementation	30.04.2041
Discount moment	2021
WACC [%]	6.27%
Cost of equity [%]	8%
Income tax [%]	19%

Table 4. Parameters used to make debt financial projection.

Parameters for projection of debt financing	
Interest rate (WIBOR3M) (WIBOR (Warsaw Interbank Offered Rate)—the reference level of interest on loans on the Polish interbank market)	0.22
Bank margin	6.61
Total interest	6.83
Loan period	20
Fixed interest rate. Equity method (fixed principal installments, interest decreases)	

Tables 3 and **4** summarize the input data that were used to prepare the financial projection of the investment project in various scenarios. **Table 3** contains the data necessary to prepare forecasts, and **Table 4** summarizes the data needed to assess debt. The purpose of the analysis was to determine the profitability or unprofitability of investing capital under an ex ante account in investment projects assuming different business models for the use of energy storage. The model was developed with the use of a combination of a quick profitability and risk analysis method for the investment, development and replacement projects with the use of Invest for Excel. Discounted cash flows (DCF) were used for the calculations (A detailed description of the performed calculations can be found in the study of Chmielewski et al.[34]). The methodology of the analysis was described in detail in the author's doctoral dissertation[33]. The criterion for accepting an investment for implementation is the profit higher than the profit offered by other investments with a similar degree of risk. Energy storage is a technology that has been defined in the Polish energy law, but there is currently no business model for its optimal and economically justified use. The only form of regulatory benefit granted to energy storage facilities in the adopted amendment is a reduced fee for connecting an energy storage facility to the grid. This fee will amount to half of the actual costs incurred for the connection. The biggest challenge still remains to supplement the current regulations regarding the use of energy storage for the needs of the prosumer market, including virtual and collective prosumers. The development of this segment would also require clarification of regulations regarding the use of storage facilities, including: to provide flexibility services to TSO and local DSOs. We therefore face further regulatory challenges to create a real market for electricity storage services. To analytically support these processes, business models were created and financial analyzes were conducted for two models in several investment scenarios. The paper presents the results of the analysis for two models of the use of an energy storage with an installed capacity of 1 MW and storage capacity of 4 MWh, assuming a very different business cost, and therefore generally addressed to different investors. The first model involves the use of Lithium-Ion technology and has been analyzed in scenarios from 1 to 4 and examines the financial attractiveness of a model based on the use of arbitration. The second model accepts the use of energy storage in lead-acid technology has been calculated for scenarios 5 and 6 and examines the profitability of using this installation as a commercial storage and reporting it to the capacity market share. In both business models, in each of the considered scenarios, the model of financing the investment with own funds (30%) and credit (70%) was adopted. The model is designed for 20 years.

2.3.1. Scenarios 1–4

Scenarios 1–4 assume the use of energy storage in Li-ion technology in arbitrage based on balancing energy prices. Electricity that will be supplied to the power grid using a 1 MW installation with a maximum capacity of 4 MWh is 2920 MWh. Maximum potential profit with assumed parameters of the energy storage reached over 3 million PLN in scenarios 1–2 where different approach were use to determining CAPEX and OPEX costs for energy storage during its lifetime. The difference in CAPEX affects the calculated level of operating costs. In scenario 1, CAPEX was adopted as LCOES and calculated according to the following formula, where[34]:

$$LCOES = \frac{CAPEX}{qN}\left[\frac{p(1+p)^n}{(1+p)^n-1}+\frac{OPEX}{CAPEX}\right]+\frac{k(1-\eta)}{\eta}$$

η—efficiency of energy storage,
LCOES—averaged lifetime costs of energy storage [PLN/MWh],
CAPEX—capital expenditure on the construction of an energy storage facility [PLN],
OPEX—operating cost of energy storage [PLN/year],
q—energy storage capacity in the cycle [MWh/cycle],
N—number of energy storage cycles in year,
p—capital rate,
k—the cost of purchasing electricity for energy storage [PLN/MWh],
n—lifetime of the energy storage [years].

For the below YoY data presented in **Table 5**, a sensitivity analysis was performed in **Table 6**. The conclusion is that the YoY for electricity prices caused by 0.5 causes a marginal increase in the profitability of the investment. The increase in YoY of the annual cost progression affects the decrease in the profitability of the investment project.

Table 5. Financial projection data used for investment projects in several business scenarios—own study using[1,16].

Data for the preparation of variable cost projections	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
LCOES [PLN/MWh]	3,260,748.76		10,138,375.40	
CAPEX [PLN/MW]	1,858,550.00		5,793,667.00	
OPEX [PLN/year]	35,498.32		185.87	
q [MWh/cycle]		0.0055		
N		730		
p		8		
k [PLN/MWh]		595.00		
n [years]		20		
η		89.00		
Data for the preparation of operating cost projections	-	-	-	-
Operating cost for 1 MW [PLN/MWh]	3,260,748.76	-	-	-
Variable costs (disposal/exchange costs)	-	844,298.65	844,298.65	844,298.65
Fixed costs (operation, repairs, liquidation)	-	51,444.00	51,444.00	51,444.00
Annual progression rate (YoY) operating costs of installation, [%]	2%	2%	2%	2%
Total revenue	5,464,507.00	5,464,507.00	2,328,403.00	2,328,403.00
Price arbitrage revenue [PLN]	5,464,507.00	5,464,507.00	2,328,403.00	2,328,403.00
Minimum balancing energy price [PLN]	247.61	247.61	268.16	-
Maximum balancing energy price [PLN]	1403.36	1403.36	760.62	-
Average price of balancing energy [PLN]	-	-		184.02
Potential profit for approx. auction [PLN]	1028.62	1028.62	438.29	163.78
Annual progression rate (YoY) of electricity prices, [%]	3.20%	3.20%	3.20%	3.20%

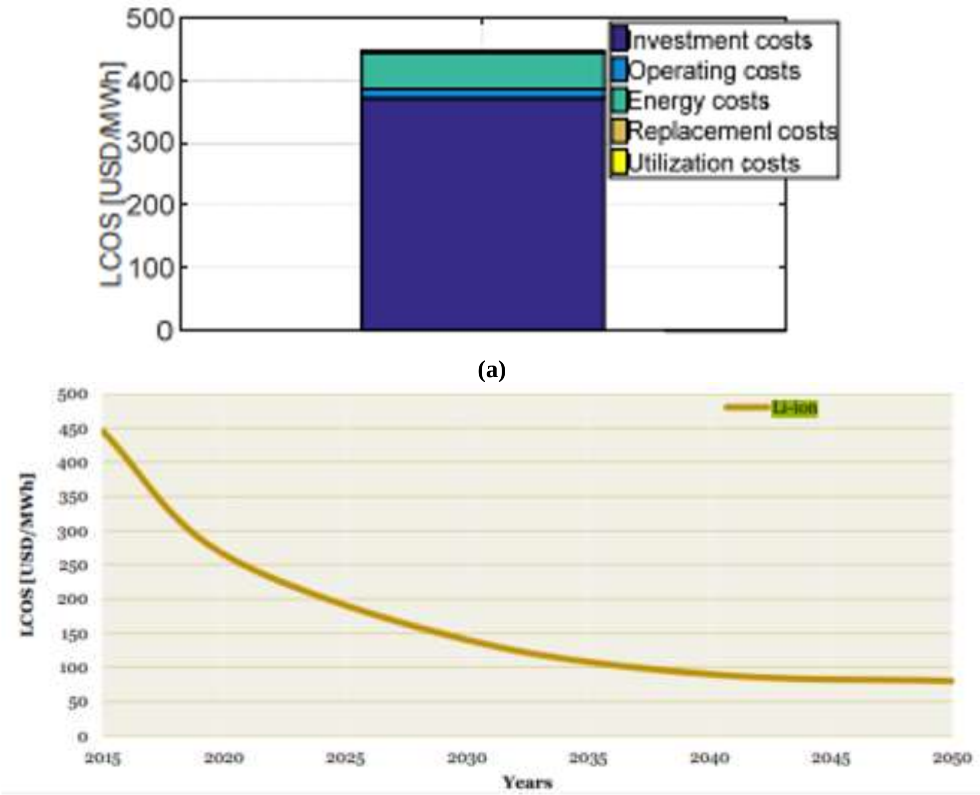
Table 6. Sensitivity analysis for YoY parameters.

Profitability ratios for the project	Basic version	Change in the annual rate of progression (yoy) of the sale price of energy and heat	Change in the annual rate of progression of operating costs	Cost-effectiveness assessment
y/y value	$rdr_{ee} = 3.2$ $rdr_{LCAES} = 2$	$rdr_{ee} = 3.7$ $rdr_{LCAES} = 2$	$rdr_{ee} = 3.2$ $rdr_{LCAES} = 2.5$	-
Net present value NPV	−1,530,085 PLN	307.778 PLN	−3,389,568 PLN	> 0
Internal Rate of Return IRR (Excel function)	0.00	0.05	−0.11	> 6.27%
IRR (by definition)	0.00	0.00	0.00	> 6.27%
Modified Internal Rate of Return MIRR	0.01	0.05	−0.07	> 6.27%
Profitability Index PI	0.18	1.17	−0.82	> 1
Payback period (discounted) DPP	20.00	19.06	20.00	-
Simple payback period PP	19.50	15.38	20.00	-
Return on equity ratios				
Net present value NPVe	−1,887,870 PLN	−620,542 PLN	−3,180,293 PLN	> 0
Internal Rate of Return IRRe (Excel function)	0.00	0.06	−0.12	> 8.00%
Internal rate of return IRRe (by definition)	0.00	0.00	0.00	> 8.00%
Modified Internal Rate of Return MIRRe	0.02	0.06	−0.06	> 8.00%
Payback period (discounted) DPPe	20.00	20.00	20.00	-
Simple payback period Ppe	19.88	15.73	20.00	-

In scenario 2, the available literature data was assumed as CAPEX. **Figure 1** shows the discounted LCOES for Li-ion energy storage, distinguishing between costs of investment, O & M (operation and maintenance), electricity, repair and decommissioning. LCOES has been presented in the perspective for the years 2015–2050 (its value does not exceed USD 450/MWh (pprox. PLN 1800/MWh) for Li-ion operating in energy arbitration. In the case of discounted annual power costs, the ACC does not exceed USD 420/kW (pprox. PLN 1700/kW) per year. In the perspective of 2050, there is a more than 80% decrease in LCOES below USD 95/MWh (pprox. PLN 380/MWh) and over 75% decrease in ACC below USD 100/kW (pprox. PLN 400/kW) per year. According to the datas on chart, the operating cost is about 1/10 of the range, so it is approximately USD 10/MWh (about PLN 40/MWh). Since the costs of replacement and disposal are much lower, we can use 1 USD/MWh in our calculations (about PLN 4/MWh). This is a value to be skipped for balancing energy prices in the first half of 2021.

In the case of scenario 1, the LCOES calculation yields a CAPEX of approximately 1.8 million PLN (**Table 7**). In the second case, the same parameter reaches the value of 5.8 million PLN. Further differences between scenarios 1–4 concern only the applied energy prices on the balancing market. In scenarios 1 and 2 we use the maximum intraday difference from the analyzed period of 1-6.2021. In scenario 3 we take a value closer to real (median) and in the last calculation we take the daily average from the entire period of the CRO price analysis. Revenues from the price arbitrage reach the break-even point of 7.65 million PLN in scenario 3. However, the break-even point for capital expenditures in the same scenario is over PLN 3.7 million. In scenario 4, calculated for the average CRO price difference over the period considered, it is not possible to obtain confirmation of the profitability of the business model. Which means that for this scenario to be profitable, the price swing in the balancing market would have to reach the level of the half-year median.

A sensitivity analysis was also performed for the tested scenarios in order to assess the impact of variables including the cost of investment outlays and the value of price arbitrage on the final financial result of the verified variant of the project implementation (**Table 8**). The result of the model will be strongly determined by both examined variables. Calculations were made for the +/−30% range, taking into account the change in NPV and IRR parameters. The decrease in the value of the investment has a positive effect on the assessment result and the change of the NPV and IRR parameters in scenarios 2 and 3. In the case of price arbitrage assessment, the results obtained for NPV and IRR in scenarios 1 to 3 achieve a positive improvement in profitability ratios with a slight increase in arbitrage income by 10%. Only scenario 4 remains unprofitable.



(a)

(b)

Figure 1. LCOES for Li-ion: **(a)** LCOS of Li-ion magazine broken down into costs; **(b)** change of LCOS in the 2015–2050 perspective. Reproduced with permission from WWF Polska[34], Copyright publisher, 2020.

Table 7. The break-even point of the examined variables in all 4 analyzed scenarios.

Analyzed indicators	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Capital expenditures [PLN]	Revenues from the sale of electricity -arbitrage [PLN]	Capital expenditures [PLN]	Revenues from the sale of electricity - arbitrage [PLN]	Capital expenditures [PLN]	Revenues from the sale of electricity - arbitrage [PLN]	Capital expenditures [PLN]	Revenues from the sale of electricity - arbitrage [PLN]
Basic	1,858,000	3,003,563	5,793,667	3,003,563	5,793,667	1,279,805	5,793,667	478,242
Breakeven point	119,534	3,141,004	17,720,096	960,434	7,658,942	960,305	2,979,338	960,305
Safety margin	−1,738,466	137,441	11,926,429	2,043,129	1,865,275	319,500	−2,814,329	482,063
Safety margin in %	−93.57%	4.58%	205.85%	68.02%	32.20%	24.96%	−48.58%	100.80%

Table 8. Sensitivity analysis for scenarios 1 to 4.

Scenarios	Sensitivity analyzes for the parameters of project variables							
	Variable-capital expenditures [PLN]	**−30%**	**−20%**	**−10%**	**0%**	**+10%**	**+20%**	**+30%**
Scenario 1	The value of the variable under study	1,300,600	1,486,400	1,672,200	1,858,000	2,043,800	2,229,600	2,415,400
	NPV-capital expenditures [PLN]	−1,207,861	−1,399,829	−1,591,802	−1,783,776	−1,975,972	−2,169,211	−2,362,450
	IRR-investment outlays [%]	1.56%	1.00%	0.49%	0.02%	−0.42%	−0.84%	−1.22%
Scenario 2	The value of the variable under study	16,619,968	18,994,249	21,368,530	23,742,811	26,117,092	28,491,373	30,865,654
	NPV-capital expenditures [PLN]	27,202,974	26,049,586	24,896,199	23,742,811	22,589,424	21,436,036	20,282,649
	IRR-investment outlays [%]	55.10%	47.84%	42.13%	37.51%	33.67%	30.43%	27.64%
Scenario 3	The value of the variable under study	4,055,567	4,634,934	5,214,300	5,793,667	6,373,034	6,952,400	7,531,767
	NPV-capital expenditures [PLN]	7,174,247	6,020,739	4,867,232	3,713,725	2,560,218	1,406,711	253,203
	IRR-investment outlays [%]	20.79%	17.07%	14.01%	11.41%	9.12%	7.08%	5.22%
Scenario 4	The value of the variable under study	−4,557,252	−5,208,288	−5,859,324	−6,510,360	−7,161,396	−7,812,432	−8,463,468
	NPV-capital expenditures [PLN]	−2,362,910	−3,741,833	−5,126,097	−6,510,360	−7,894,623	−9,278,886	−10,663,149
	IRR-investment outlays [%]	−3.33%	−8.15%	−14.04%	-	-	-	-
	Variable-price arbitrage [PLN]	**−30%**	**−20%**	**−10%**	**0%**	**+10%**	**+20%**	**+30%**
Scenario 1	The value of the variable under study	2,102,494	2,402,850	2,703,207	3,003,563	3,303,919	3,604,276	3,904,632
	NPV-capital expenditures [PLN]	−14,542,022	−10,227,215	−5,914,529	−1,783,776	2,020,243	5,534,563	9,024,947
	IRR-investment outlays [%]	-	-	-	0.02%	12.28%	22.69%	33.08%
Scenario 2	The value of the variable under study	2,102,494	2,402,850	2,703,207	3,003,563	3,303,919	3,604,276	3,904,632
	NPV-capital expenditures [PLN]	13,271,660	16,762,044	20,252,427	23,742,811	27,233,195	30,723,578	34,213,962
	IRR-investment outlays [%]	24.71%	29.08%	33.33%	37.51%	41.62%	45.70%	49.74%
Scenario 3	The value of the variable under study	895,864	1,023,844	1,151,825	1,279,805	1,407,786	1,535,766	1,663,747
	NPV-capital expenditures [PLN]	−767,556	738,552	2,226,139	3,713,725	5,201,311	6,688,898	8,176,484
	IRR-investment outlays [%]	3.23%	6.27%	8.95%	11.41%	13.70%	15.88%	17.97%
Scenario 4	The value of the variable under study	334,770	382,594	430,418	478,242	526,067	573,891	621,715
	NPV-capital expenditures [PLN]	−8,571,919	−7,884,732	−7,197,546	−6,510,360	−5,823,173	−5,135,987	−4,448,801
	IRR-investment outlays [%]	-	-	-	-	−15.03%	−10.40%	−7.12%

2.3.2. Scenarios 5 & 6

The next two scenarios 5 and 6 concern a business model in which revenues are obtained simultaneously from two sources, which include: (i) commercial storage service for PV installations and participation in the capacity market auctions, (ii) provision of capacity services. Annual revenues from participation in the Capacity Market were calculated on the basis of the auction results for 2021[35]. Revenue from the sale of stored electricity from consumers for a fee was determined taking into account reference prices[36]. The models differ in the number of customers: in scenario 5 we have 2500 and in the second one, number 6, there are twice as many—5000 signed contracts and we assume a higher contract value—PLN 300/year (**Table 9**).

Table 9. Financial projection data used for investment projects in business model for CM in scenarios 5 & 6—own study using.

	Capacity Market	
Data for the preparation of operating cost projections	**Scenario 5**	**Scenario 6**
Variable costs (disposal/exchange costs) [PLN]	800,029	
Fixed costs (operation, repairs, liquidation) [PLN]	1600	
Annual progression rate (YoY) operating costs of installation, [%]	2%	
Total revenue	2,721,000	3,721,000
Revenue form capacity market [PLN/MW/year]	198,000	
Revenue from contracts with prosumers [PLN]	500,000	1,500,000
Revenue from the sale of electricity [PLN]	2,023,000	
Capacity auction price for 2021 [PLN/kW/year]	198	
Contract cost/year [PLN]	200	300
The number of concluded contracts	2500	5000
Contract price [PLN]	595	

With such assumptions, we also had to change the technology to acid-Pb, which is characterized by a greater number of possible daily cycles. However, it is also characterized by a shorter life-time and higher investment expenditures[31]. In such a model, LCOES has a value of 14 million PLN, and CAPEX is 8 million PLN. OPEX was calculated as 1.6 thousand PLN. For lead acid technology, q is defined as 0.0047 MWh/cycle, the number of cycles as 850 and the service life of such a technology as 15 years. The energy storage efficiency is about 90%. Electricity that will be supplied to the power grid using a 1 MW installation with a maximum capacity of 4 MWh is 3400 MWh. Such business model is definitely more profitable.

A detailed sensitivity analysis was also performed for both scenarios. In **Table 10** the results for scenario number 6 are summarized which is more profitable. The results indicate that the model result is most sensitive to changes in the number of concluded contracts and electricity sales. Revenues from participation in the capacity market are of marginal importance for the profitability of the model. The result of the analysis was used to prepare projection charts (**Figure 2**). It is worth noting that revenues from the Capacity Market, scenarios 5 & 6, under the current conditions (the auction price for 2021 is PLN 198/kW/year) remain at a marginal level and does not affect the result of the simulation. The results of the financial projection are summarized in **Table 11**.

Table 10. Sensitivity analysis result for scenario no. 5 & 6.

Work table for performing sensitivity analysis and projection charts scenario 5							
Variable-capital expenditures [PLN]	−30%	−20%	−10%	0%	+10%	+20%	+30%
The value of the examined variable	5,600,000	6,400,000	7,200,000	8,000,000	8,800,000	9,600,000	10,400,000
NPV-capital expenditures [PLN]	54,049,591	53,300,345	52,551,099	51,801,853	51,052,607	50,303,361	49,554,115
IRR-capital expenditures [%]	52.06%	47.02%	43.02%	39.73%	36.99%	34.65%	32.62%
Variable-participation in Power Market (PM)/DSR [PLN]	−30%	−20%	−10%	0%	+10%	+20%	+30%
The value of the examined variable	138,600	158,400	178,200	198,000	217,800	237,600	257,400
NPV-participation in PM/DSR [PLN]	51,309,928	51,473,903	51,637,878	51,801,853	51,965,827	52,129,802	52,293,777
IRR-participation in PM/DSR [%]	39.26%	39.42%	39.58%	39.73%	39.89%	40.05%	40.21%
Variable-sale of electricity from storage [PLN]	−30%	−20%	−10%	0%	+10%	+20%	+30%
The value of the examined variable	1,416,100	1,618,400	1,820,700	2,023,000	2,225,300	2,427,600	2,629,900
NPV-sale of electricity from storage [PLN]	46,321,642	48,148,379	49,975,116	51,801,853	53,628,589	55,455,326	57,282,063
IRR-sale of electricity from storage [%]	35.25%	36.72%	38.22%	39.73%	41.27%	42.82%	44.39%
Variable-contracts for the storage of surplus energy from prosumers [PLN]	−30%	−20%	−10%	0%	+10%	+20%	+30%
The value of the examined variable	350,000	400,000	450,000	500,000	550,000	600,000	650,000
NPV-contract for the energy storage [PLN]	50,058,322	50,639,499	51,220,676	51,801,853	52,383,029	52,964,206	53,545,383
IRR-contract for the energy storage [%]	38.51%	38.92%	39.32%	39.73%	40.14%	40.55%	40.97%
Work table for performing sensitivity analysis and projection charts scenario 6							
Variable-capital expenditures [PLN]	−30%	−20%	−10%	0%	+10%	+20%	+30%
The value of the examined variable	5,600,000	6,400,000	7,200,000	8,000,000	8,800,000	9,600,000	10,400,000
NPV-capital expenditures [PLN]	65,673,129	64,923,883	64,174,637	63,425,391	62,676,145	61,926,899	61,177,653
IRR-capital expenditures [%]	63.93%	57.40%	52.25%	48.07%	44.59%	41.65%	39.12%
Variable-participation in Power Market (PM)/DSR [PLN]	−30%	−20%	−10%	0%	+10%	+20%	+30%
The value of the examined variable	138,600	158,400	178,200	198,000	217,800	237,600	257,400
NPV-participation in PM/DSR [PLN]	62,933,466	63,097,441	63,261,416	63,425,391	63,589,366	63,753,341	63,917,316
IRR-participation in PM/DSR [%]	47.57%	47.74%	47.90%	48.07%	48.23%	48.40%	48.56%

Table 10. (*Continued*).

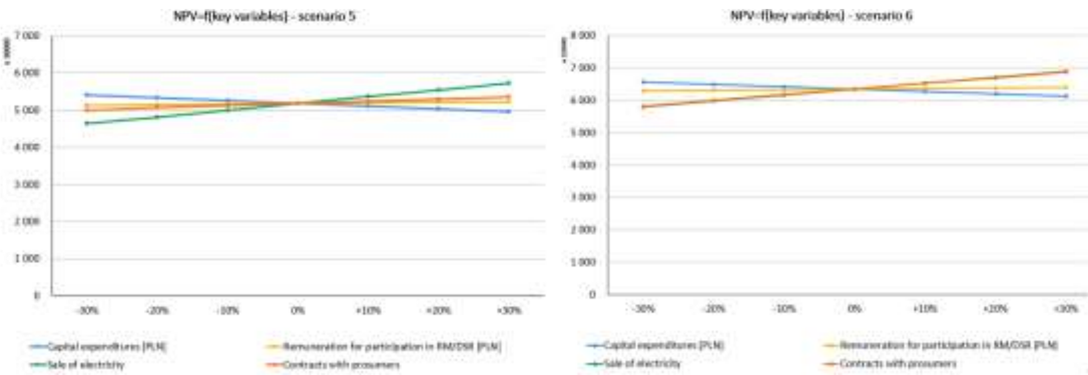
Work table for performing sensitivity analysis and projection charts scenario 6							
Variable-sale of electricity from storage [PLN]	−30%	−20%	−10%	0%	+10%	+20%	+30%
The value of the examined variable	1,416,100	1,618,400	1,820,700	2,023,000	2,225,300	2,427,600	2,629,900
NPV-sale of electricity from storage [PLN]	57,945,181	59,771,917	61,598,654	63,425,391	65,252,128	67,078,865	68,905,602
IRR-sale of electricity from storage [%]	43.35%	44.91%	46.48%	48.07%	49.67%	51.29%	52.92%
Variable-contracts for the storage of surplus energy from prosumers [PLN]	−30%	−20%	−10%	0%	+10%	+20%	+30%
The value of the examined variable	1,050,000	1,200,000	1,350,000	1,500,000	1,650,000	1,800,000	1,950,000
NPV-contract for the energy storage [PLN]	58,194,799	59,938,330	61,681,860	63,425,391	65,168,922	66,912,453	68,655,984
IRR-contract for the energy storage [%]	44.28%	45.54%	46.80%	48.07%	49.34%	50.61%	51.89%

Table 11. The results of the financial projection—own calculation.

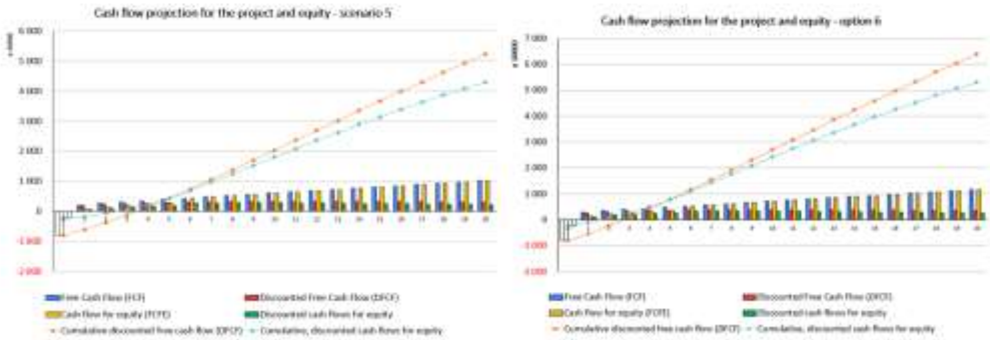
Financial projection results for investment projects	**Profitability limit**	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**
Profit account							
Operating flows [PLN]	-	589,103	3,848,353	1,316,212	76,362	10,179,632	11,648,597
EBITDA profit [PLN]	-	714,212	4,671,652	1,535,547	77,231	12,490,220	14,309,562
Depreciation [PLN]	-	−130,060	−405,557	−405,557	−405,557	−560,000	−560,000
Assets value at the end of the year [PLN]	-	−743,200	−2,317,467	−2,317,467	−2,317,467	−3,200,000	−3,200,000
EBIT operating profit [PLN]	-	584,152	4,266,096	1,129,991	−328,326	11,930,220	13,749,562
EBT profit [PLN]	-	584,152	4,266,096	1,129,991	−328,326	11,930,220	13,749,562
Income tax [PLN]	-	−110,989	−810,558	−214,698	-	−2,266,742	−2,612,417
Flow account							
Free cash flow (FCF) [PLN]	-	589,103	3,848,353	1,316,212	76,362	10,179,632	11,648,597
Discounted free cash flow (DFCF) [PLN]	-	174,487	1,139,851	390,043	29,047	3,016,605	3,451,914
Cumulative, discounted free cash flow (CDFCF) [PLN]	-	−1,722,023	24,157,514	4,184,399	−6,004,711	52,265,094	63,856,105
Free cash flow for equity (FCFE) [PLN]	-	589,103	3,848,353	1,316,212	76,362	10,179,632	11,648,597

Table 11. (*Continued*).

Financial projection results for investment projects	Profitability limit	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Flow account							
Discounted free cash flow for equity (DFCFE) [PLN]	-	126,391	825,657	282,391	−1,919,119	2,184,022	2,499,186
Cumulative, discounted free cash flow for equity (CDFCFE) [PLN]	-	−1,934,652	20,211,256	3,024,742	−5,661,769	43,038,945	53,009,319
Profitability indicators for the project							
Net present value (NPV) [PLN]	>0	−1,783,776	23,742,811	3,713,725	−6,510,360	51,801,853	63,425,391
Internal rate of return (IRR)	>6,27%	0%	38%	11%	−16%	40%	48%
Modified internal rate of return (MIRR)	>6,27%	2%	15%	8%	−14%	17%	19%
Profitability indicator (PI)	>1	0.04	5.10	1.64	−0.12	3.21	3.70
Payback period (discounted) (DPP)	-	20.00	3.18	10.41	20.00	3.45	2.72
Payback period (PP)	-	19.50	2.82	7.71	20.00	3.09	2.46
Return ratios for equity							
Net present value (NPVe) [PLN]	>0	−1,996,404	19,796,652	2,554,068	−6,396,476	42,575,703	52,578,606
Internal rate of return (IRRe)	>8.00%	−1%	67%	13%	-	64%	87%
Modified internal rate of return (MIRRe)	>8.00%	2%	22%	11%	−14%	25%	26%
Payback period (discounted) (DPPe)	-	20.00	1.99	10.98	20.00	2.56	1.66
Payback period (PPe)	-	19.95	1.79	8.48	20.00	2.32	1.52



(a) Result of the sensitivity analysis of the NPV indicator for scenarios 5 and 6.



(b) Cash Flow projection for scenarios 5 and 6.

Figure 2. Sensitivity analysis results for scenarios 5 and 6: **(a)** Result of the sensitivity analysis of the NPV indicator for scenarios 5 and 6, **(b)** Cash Flow projection for scenarios 5 and 6.

3. Results and discussion

3.1. Cost of energy storage use and competitiveness of scenarios

When determining the initial assumptions for the DCF model of discounted cash flows, it was assumed that the reference period for the created analysis would be 20 years. The period covers the implementation of the investment and its operation. As part of the income statement, financial parameters were defined, including: income, EBIT, EBT, EBIDTA and operating cash flow.

Operating cash flows, which include the sum of revenues, operating expenses, adjusted income tax and change in working capital reached a positive value for each of the analyzed scenarios. EBIT and EBT for the scenarios under consideration, excluding 4, remain positive. Contrary to EBIT, the EBITDA ratio does not include the costs related to the investments and only includes operating and non-operating costs from continuing operations. EBIDTA remains positive regardless of the chosen business model. Values for all scenarios except 4, indicate the profitability of the investment.

The cash flow statement, right after the profit and loss account, is another important element of the financial statement. The purpose of this stage of the analysis is to explain the sources of the increase or decrease in the balance sheet and to determine the company's need for external funds. There are two methods of enterprise valuation based on discounted cash flows. The first one is the FCFF method (Free Cash Flow to Firm). When valuing FCFF, free cash flows will be discounted at the weighted average cost of capital. The second most frequently used variant of the discounted cash flow (DCF) model is the FCFE (Free Cash Flow To Equity) method. It is characteristic for FCFE that free cash flows are discounted only at the cost of equity. FCFE reaches the value of operating cash flow in each of the analyzed scenarios 1–6. The positive value of cash flows from operating activities should generally be assessed positively, because it means that the company creates a financial surplus from the basic spheres of its economic activity. The DFCF also assumes positive values in each analyzed scenario, with the highest value of the results appearing in variant no. 2, and in variant no. 1 the best financial results are obtained in scenario no. 2. Using the calculated WACC, we discount each forecasted flow. The sum received is the first element of goodwill, which was estimated on the basis of the discussed two-phase valuation model. In the assessed variants, the DFCFF index reached a positive value for each analysis for scenarios 1–6 in both analyzed business models of warehouse use. The adopted assumptions show a positive result, so the models are profitable and reasonable, with the results in variant 2 being significantly more favorable, and in variant 1 the most profitable scenario is no. 2.

The last stage of the analysis is the interpretation of the results of the economic efficiency assessment of the planned project. The profitability analysis was performed on two levels: project and equity. In the first case, free cash flows are the basis for the calculations. In the second case, free cash flows adjusted for cash flows from external capital financing are the basis. Based on the free flow assessment, we conclude that option 2 scenario 6 achieves profitability slightly faster than scenario 5 (**Figure 2**). The parameters NPV (**Figure 2**), IRR, MIRR and DPP and PP were tested (**Table 11**). The results of this analysis also confirm that variant 1 in scenario 2 and variant 2 (scenarios 5 & 6) are the most financially advantageous. The internal rate of return (IRR) for which NPV equals zero is greater than the discount rate $r = 4.95\%$, in the case of scenarios 2, 3, 5 and 6. With this result, we consider the investment projects profitable. The MIRR is higher than the discount rate r, which confirms that the project is profitable for scenarios 2, 3, 5 and 6. The PP indicator shows that scenario 6 gives the fastest return on investment. Scenarios 2 and 5 are also worth considering. Exactly the same can be assessed based on the discounted result of DPPe. In turn, on the basis of these two indicators, scenarios 4 and 1 are the least profitable. The analysis of profitability indicators for equity gives us the same results as for the project.

3.2. Remarks to Act introducing energy storages to legislation

The analysis performed in chapter 1.1.2 shows that the Polish photovoltaic industry is ahead of the goals assumed by the government and analysts. The UC74 Act is intended to transpose into Polish law the provisions of Directive 2019/944 of the European Parliament and of the Council of 5 June 2019 concerning common rules for the internal market in electricity and amending Directive 2012/27/EC Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing guidelines for balancing Regulation (EU) No. 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market in electricity for a civic energy community. The UC74 Act transposes into Polish legislation provisions concerning the civic energy community[37]. Perhaps it will be an impulse and an opportunity to increase consumption of local generation and a new way of shaping the market. The best results will be obtained by combining units with different energy demand profiles. Then energy trading will be simpler, better managed and less wasteful. This can be beneficial for the environment and the economy. The sale of overproduced energy to the operator is currently the least favorable option, because energy is sold at the average selling price of electricity on the energy market from the previous quarter. A better option is to sell the produced energy to an aggregator. Aggregators use a dynamic price, which is shaped depending on the needs of the market in 15-minute intervals. In order to hit the right price window, it will be necessary to have a storage installation. Energy storage technology should be used to optimize the use of PV installations. For households, energy storage technologies can also provide an emergency energy management system. In addition, they can allow for the coordination of renewable (solar) energy production with demand and with the market price. The mismatch between the efficiency of the photovoltaic installation and the demand generates too much energy at noon, which is not received from the power grid and may lead to its overload as a result of noticing too high voltages. Currently, as a result of security measures, prosumer installations are disconnected. However, this is not an effective solution, because we do not use effective PV generation. It is necessary to shift the energy consumption in relation to its generation, which increases the economic efficiency of the use of panels and allows to achieve the benefits of using PV installations. However, it is not always necessary to build an energy storage next to a PV installation in order to profitably use the surplus electricity produced. It is possible to modify the home installation to use electricity generated by photovoltaic panels. The most commonly used solutions of this type include heating utility water or powering an air-conditioning system or a heat pump. Solutions consisting in charging electric cars with energy obtained from photovoltaic installations are also becoming more and more popular. The development of the Vehicle to Grid solution also stimulates the development of energy storage[38]. In this case, the vehicle becomes a storage and backup power source. Using the interaction of electric vehicles and the power system, the functions of peak load shifting and frequency control can be implemented. Therefore, the best solution is to regularly use as much electricity as possible from prosumer production. Only then can energy losses be eliminated. Therefore, photovoltaics should always be optimally adapted to the user's needs, without unnecessary oversizing of the installation. Hence it is necessary to consider introducing incentives to invest in own generation installations and a) optimal selection of the size of the installation or the use of storage technology, b) in the case of prosumers with oversized installations, incentives to expand their systems or introduce automation ensuring rational consumption of their own generation—e.g., by changing the heating system to a heat pump or adding an air conditioning system or c) adequate stimulation of the market for the development of Vehicle to Grid technology.

4. Conclusions

The aim of the research was to compare and evaluate the currently most popular energy storage devices and systems, taking into account the needs of end users. The economic and environmental issues as well as challenges and limitations have been elaborated through deep and strong consultation of literature, previous research, reports, legal provisions, incentive systems and journal.

Energy storage is nowadays recognised as a key element in modern energy supply chain. This is mainly because it can enhance grid stability, increase penetration of renewable energy resources, improve the efficiency of energy systems, conserve fossil energy resources and reduce environmental impact of energy generation. This technology may allow flexible generation and delivery of stable electricity for meeting demands of customers. Energy storage can be included among the key technologies for the success of the energy transformation and the potential for predicting and designing changes in the electricity market model. Energy storage will soon enter the initial commercialization phase from the demonstration project stage in Poland. To properly realize the commercialization of energy storage on a large scale, it is necessary to analyze energy storage business models. A first approach is provided in this publication. Long-term use of the energy accumulated in the storage requires a high energy capacity (Energy Capacity), while the possibility of using the storage in abrupt load changes requires appropriate power (Power Capacity). In the first case, the changes concern price arbitrage, so we manage energy consumption over time. In turn, in the second considered case, we regulate power consumption, so this applies to variant 2 of the business model analyzed in this paper, which assumes management of the power of storage installation. The dynamic growth of home PV installations in the power system has a negative impact on the DSO network, which is not adapted to the management of such an organized system. Distributors do not have SCADA systems and full network models. Transformer overloads are becoming a frequent phenomenon. Investments in the network, new services or the widespread installation of home warehouses are necessary. The dynamic growth of PV in the system forces the search for solutions that will increase the efficiency of using these installations. In order to eliminate the duck curve phenomenon and its negative impact on the operation of the PPS, it is proposed to include energy storage technology in the installation operation scheme. It will allow for:

- eliminate the negative phenomena of overloads in EPS at the DSO network level,
- avoid the need for costly network investments,
- increase the economic efficiency of PV installations, optimize expenses.

The article distinguishes two groups of energy storage applications. In variant 1, covering scenarios 1–4, energy management (participation in price arbitrage) and operational activities in variant 2 (control of system operation and parameters within the capacity market), covering scenarios 5 and 6. Financial analysis for the two business models (variants 1–2) quoted in 6 different scenarios clearly shows that the use of energy storage may already be a source of real profits for investors. Commercial use of energy storage (scenarios 5 and 6) stands out in terms of the achieved financial benefits. Comparative charts for scenarios 5 and 6, which illustrate how the NPV of key variables is shaped and cash flow projection for the model, assuming that energy storage performs a commercial function for prosumers, confirm the profitability of such scenarios for the use of electricity storage facilities. The payback period occurs in the first few years after the investment is launched (2–3 years). Hardly any form of investing allows such a quick return of capital. On the other hand, price arbitrage remains uncompetitive despite the introduction of significant simplifications in the model, which involve the use of CRO prices from the balancing market. The results for scenarios 2 and 3 should be further verified on stock prices before being considered objectively positive.

Author contributions

Conceptualization, AW and RK; methodology, AW and RK; software, AW; validation, AW and RK; formal analysis, AW; investigation, AW; resources, AW; data curation, AW; writing—original draft preparation, AW; writing—review and editing, AW and RK; visualization, AW; supervision, AW and RK; project administration, AW; funding acquisition, AW and RK. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

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