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Preliminary techno-economic analysis of electrochemical cell types applied to stationary energy storage systems

Wstępna analiza techniczno-ekonomiczna różnych rodzajów ogniw elektrochemicznych w zastosowaniu do stacjonarnych magazynów energii

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Abstract: The article presents a techno-economic analysis of various lithium-ion and lead acid battery types for application in stationary energy storage systems. The analysis was conducted using public data provided by manufacturers and vendors. The study presents a criterion making an economic comparison between different battery electrochemical types much easier. The obtained results demonstrate that the commonly used electrochemical cell type in stationary storage systems might not be economically optimal when considering a long-term operational horizon.

Keywords: techno-economic analysis, electrochemical cell technologies, stationary energy storage

Streszczenie: W artykule przedstawiono analizę techniczno-ekonomiczną różnych rodzajów akumulatorów litowo-jonowych oraz kwasowo ołowiowych, w zastosowaniu do stacjonarnych magazynów energii. Analizę przeprowadzono na podstawie ogólnodostępnych danych, udostępnianych przez producentów i sprzedawców. W pracy przedstawiono kryterium ułatwiające porównanie ekonomiczne różnych typów akumulatorów elektrochemicznych. Otrzymane wyniki pokazują, że powszechnie stosowany typ ogniw litowo-jonowych w magazynach stacjonarnych może nie być optymalnym ekonomicznie wyborem, uwzględniając długi horyzont czasowy ich eksploatacji.

Słowa kluczowe: analiza techniczno-ekonomiczna, ogniwa elektrochemiczne, stacjonarny magazyn energii

Introduction

Currently, stationary energy storage systems are growing in popularity due to their high availability, good technical performance and continuously decreasing price. The development of electrochemical cell technology and the decrease in their prices are driven by the expansion of renewable energy sources (mainly photovoltaics) and the growing popularity of electromobility. Therefore, there is a continuous need to analyse the current technical parameters of cells in relation to the requirements of the target application, as well as their availability and cost, which change over time.

Analysing electrochemical cell technologies for stationary energy storage systems is a complex and multi-criteria task. The complexity is related to several cell technical parameters and their changes during operation conditions, which are difficult to predict over a long exploitation time. Usually, the cell capacity, average cell voltage, number of charge-discharge cycles, and energy transfer efficiency are considered during the cell technology selection. All those parameters are

subject to change depending on thermal conditions, the cell's load current/power, and the ongoing ageing processes occurring during storage and cyclic operation. Considering all existing cell types and variations of cell parameters for a given application is very difficult. Therefore, the analysis presented in this publication is used for the first stage of a battery type selection. The analysis aims to make a preliminary selection of the cell types based on cell data from many samples in the Polish market in 2025. The proposed analysis indicates the most promising electrochemistry/type of cells for further evaluation processes. Therefore, it mainly focuses on nominal operation conditions. The important aspect of the presented analysis is a consideration of the economic costs of cell exploitation during the entire lifetime of the battery.

A wide range of comparison methods is available for energy storage in stationary systems. The battery system designers might prefer various battery technologies, depending on the prioritization of the selection criteria, such as instantaneous and continuous power, total stored energy, storage duration, location, and availability of natural resources. A comparative analysis of energy storage systems, including non-electrochemical technologies, has been presented in [1] and [2]. The articles discuss technical and economic issues; however, all Li-ion cell types were classified under one common category, which results in a wide range of parameter values without distinguishing for each type of chemistry. Reference [3] compares selected energy storage technologies in a photovoltaic system, where, in order to utilise the available solar energy more efficiently, an energy storage system should be implemented and operated as an electrical energy buffer. Unfortunately, the analysis was conducted solely for energy storage systems employing $LiFePO_4$ cell technology and does not give any information on other electrochemical battery types. The authors of [4] and [5] addressed the issue of economic comparison of various technologies employed in stationary energy storage systems, but exclusively in terms of the cost of installed energy, i.e. the purchase cost of a storage unit with specified technical parameters, without accounting for the lifetime of energy storage systems based on different battery chemical types. References [6] and [7] present a comparison of electrochemical energy storage technologies in the context of electric or hybrid vehicles, where the analysis is limited to selected electrochemical cell specimens dedicated to the mobile application. In our study, the goal is different, aiming to give the technical and economic guidelines for battery type selection for stationary systems rather than mobiles. Another aim is to propose universal information about various battery types. It is achieved by statistically treating various electrochemical cell data and minimising single-sample errors. Article [8] compares various electrochemical cell technologies from a technical point of view, also considering the economic aspect (based on 2017 data) of installed energy cost. However, economic conclusions drawn from installed energy costs might sometimes be insufficient. Despite a very comprehensive comparison, it does not consider the operational cost of the stored energy. The long-term energy operation cost is more important for an investment than the initial purchase cost, because the operation cost determines profits from investment in battery energy storage. The purchase cost gives only information about the required amount of money to realise the investment. Therefore, the stored energy operational cost (explained more in the further study), provides a more reliable assessment of the economic competitiveness of the analysed electrochemical cell types. The stored energy operational cost has been considered in criterion called the levelized cost of stored energy (*LCOE*) in publications [9], [10], [11]. The authors of comparison in [9], used this criterion to compare redox-flow ZnBr, lead acid and Li-Ion $LiFePO_4$ battery types in years 2015÷2017, approximately. The similar comparison of the same battery types is presented in publication [10] (2014). The presented criterion in this publication is a variant of *LCOE* criterion adapted to analysis using suppliers' datasheets only. Therefore, it does not consider power losses (efficiency) in the operation costs, as it is in [9], [10]. However, the delivered energy from battery can be calculated using the average voltage and nominal cell capacity and does not require information about efficiency. Another difference in the presented criterion is the consideration of battery/cell capacity change during cyclic ageing in the output energy calculation, which improves the accuracy of the factor, which was not considered in any of the mentioned publications.

This analysis solely provides an initial overview of the market in Poland and highlights the characteristics of seemingly expensive or inexpensive cell technologies. The article begins with a brief introduction and a review of electrochemical cell parameters of different types (the three most popular types of lithium-ion batteries and lead acid battery). High expectations are associated with Na-ion cell electrochemistry type, which has comparable parameters to Li-ion [12]. However, due to the currently limited selling market for cells of Na-ion type, it was not considered in the analysis herein. The next part of the publication concerns the data acquisition and analysis method, which is presented and illustrated using a representative LFP battery type.

The main part of the article provides a comparison of selected Li-ion and lead–acid cell types, introducing a criterion for economic evaluation. The article concludes with a discussion of the findings derived from the conducted analysis.

Methodology description

The presented study began with collecting data from different sale offers with technical parameters of electrochemical cells, representing a given cell type. The Li-ion cell types were grouped according to their cathode and anode chemistry: $LiFePO_4$ (LFP), $LiNi_xMn_yCo_{1-x-y}O_2$ (NMC), $Li_4Ti_5O_{12}$ (LTO). Besides the Li-ion cells, the lead-acid (LA) batteries were included in the data analysis due to their popularity in stationary applications. Next, the values of the adopted technical and economic evaluation criteria were determined for every cell and subjected to statistical analysis. The collected data were illustrated on graphs for the LFP type only to make the explanation easier. This analysis stage concluded with the calculation of medians, which were used as representative values for the investigated cell types. Finally, the analysis concludes with a graphical comparison of the evaluation criteria for the mentioned battery chemistry types. The evaluation criteria were designed mostly for battery selection in a stationary application under continuous operation. Therefore, the power requirements criteria were not considered, since the stationary energy systems often require the average power capability of half of their nominal value which is already installed in cells (discharge rates with about 0.5 C-rate).

Data collection

The presented analysis concerns intensively cycled battery storage systems (at least one cycle per day, approximately), and the necessary data is derived only from the cell sale offers. Data were collected during 22-26 May 2025 from internet sale offers available in Poland. A dataset of 20 sale offers for electrochemical cells representing the considered technologies was compiled for comparative analysis (giving 80 offers in total). The offers varied in cell capacity, purchase cost, manufacturer and sales platform, but all included the essential information required for this study. The information used for the analysis is limited to the cell price and its parameters provided by the manufacturers/sellers: nominal capacity, average voltage, weight, and the cycle life at the declared depth of discharge. In view of the relatively high capacities of stationary energy storage systems, the analysis was limited to prismatic and pouch cells; the cylindrical and button casing formats were omitted. The cost price was determined based on the price threshold for a quantity of several new cells.

Evaluation criteria

A direct comparison of the basic cell parameters does not provide sufficient information for a reliable comparison and battery selection for a stationary energy storage system. Therefore, the electrochemical cell types were compared to four criteria derived from the fundamental cell parameters. Those criteria include:

- energy density [Wh/kg];
- installed energy cost *IEC* [PLN/kWh] – defined as:

$$IEC = \frac{CP}{Q_{\text{cell\_N}} \cdot U_{\text{cell\_AV}}} \tag{1}$$

where:
CP – cost price,
$Q_{\text{cell\_N}}$ – nominal cell capacity,
$U_{\text{cell\_AV}}$ – average cell voltage;

- number of cycles n [-] – defined as the number of complete cycles (discharge and charge) until the cell's capacity drops below 80% of its nominal value (ISO 12405-2), typically measured at 80% depth of discharge (DoD);
- levelized cost of stored energy *LCOE* [PLN/kWh] – defined as:

$$LCOE = \frac{CP}{DoD_{\text{cycle}} \cdot n \cdot \mathrm{d}Q_{\text{AV}} \cdot U_{\text{cell\_AV}} \cdot Q_{\text{cell\_N}}} \tag{2}$$

where:
CP – cost price,
DoD_{cycle} – depth of discharge of single cycle,
$\mathrm{d}Q_{\text{AV}}$ – average capacity correction factor caused by cyclic ageing,
$Q_{\text{cell\_N}}$ – nominal cell capacity,
$U_{\text{cell\_AV}}$ – average cell voltage,
n – cycle lifetime given in number of cycles at given DoD_{cycle}.

The installed energy cost reflects the initial capital expenditure borne by the investor. However, this metric does not account for the life-time performance of the storage system specific to the chemistry type. Moreover, this criterion does not consider that some cell types are more expensive but may operate longer. Therefore, another criterion for more reliable comparison has been used, which is the levelized cost of stored energy (*LCOE*).

The levelized cost of stored energy is an adaptation of existing approach introduced by the authors of this publication. The presented form of *LCOE* criterion says how much it costs to store a unit of energy while the energy storage system is being operated and fully utilised. The denominator of eq. 2 is the value of

the energy which the cell/battery can deliver during its entire lifetime. The criterion considers the lifetime of a cell and the simplified ageing process by considering a linear cell capacity drop during energy cycling. The *LCOE* criterion is more useful in economic comparisons, and it will be presented together with the analysis results. In estimating capacity drop, a linear decrease in cell capacity operation was assumed, which can be justified by the data presented in [13] and [14]. Thus, the average capacity factor (dQ_{AV}) in eq. 2 was assumed 0.9 since it is the average capacity value between the new cell ($Q_{cell\ new} = 1.0\ Q_{cell\ N}$) and when this cells assumed to be depleted ($Q_{cell\ depleted} = 0.8\ Q_{cell\ N}$).

Analysis constraints

In the presented simplified analysis of the electrochemical cell, the following assumptions were made:

- cell types were limited to those applicable in stationary energy storage systems;
- no transport or disposal costs (taxes, discount rate, etc.) for the cells were considered;
- exchange rates were set at USD/PLN = 4.00 and EUR/PLN = 4.25;
- the costs concerns the cells only, the other battery system component costs, such as battery management system and construction components, are not included;
- self-discharge effects were not taken into account;
- energy losses during charging processes were neglected (battery operation efficiency);
- cells were considered fully depleted once their capacity dropped to 80% of the nominal value;
- the analysis of power demand and the impact of the HVAC system was omitted;
- the aging process related to cyclic operation was simplified to linear capacity fading, and the aging process related to cell storage (calendar ageing) was not considered (assumes that the cell is continuously in operation).

Results

Twenty sales offers for cells of each electrochemistry type were used to compute the previously defined evaluation criteria. The variation of criteria values for each considered electrochemistry type was presented in Appendix 1. Only the values for the popular LFP type were illustrated in histograms in the next paragraph and used for explanation. Then, those values were used to calculate medians as the representative values for each electrochemistry type. Finally, the comparison results were compared in the graph and discussed.

Analysis criteria on the example of LFP electrochemistry type

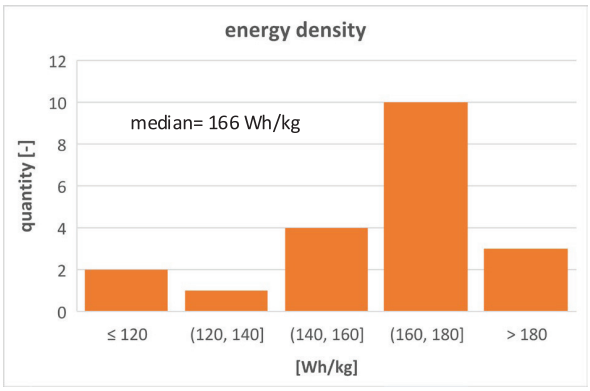
The illustrative histograms of the criteria values for LFP cells are presented in Fig. 1. Fig. 1a presents the distribution of values of the energy density of LFP cells. It can be noticed that half of the sale offers have an energy density ranging from 160 to 180 Wh/kg, consistent with the median value of 166 Wh/kg. The comparison of the installed energy cost (*IEC)* is a widely used economic criterion and its values distribution is presented in Fig. 1b. The majority of *IEC* falls within the range of 400÷600 PLN/kWh. The median installed energy cost for LFP type is approximately 560 PLN/kWh. The levelized cost of stored energy was obtained by incorporating the cells' cycle life and considering the cells' purchase costs. The presented *LCOE* says how much it costs to store 1 kWh of energy, when the energy storage system is being used (usage cost of 1 kWh). Fig. 1d presents the distribution of *LCOE*, with the most frequent values falling within the range of 0.1÷0.25 PLN/kWh and a median value of 0.223 PLN/kWh.

In analysing cell specifications, careful consideration should be given to the declared cycle life, since manufacturers report this parameter at different Depth of Discharge (DoD) values. Fig. 1c shows a histogram of the cycle life declared by manufacturers at DoD= 80% for LFP cell technology. The median cycle life is 4000 cycles, although numerous offerings report values below 2500 and above 5500 cycles.

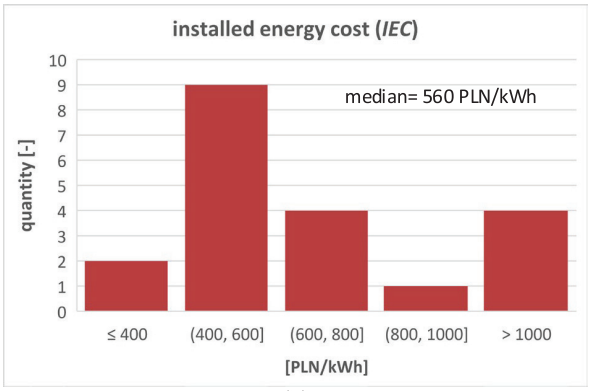
The same procedures of data collection and calculations of comparison criteria were carried out for the remaining three electrochemical cell types: $LiFePO_4$ (LFP), $LiNi_xMn_yCo_{1-x-y}O_2$ (NMC), $Li_4Ti_5O_{12}$ (LTO), as well as the still widely used lead-acid (LA). The numeric data for other chemistry types are presented in Appendix 1.

Technologies comparison

The comparison was based solely on the median values (the representative values) of four criteria for each of the mentioned chemistries. The comparison between the chemistry cell types is presented in Fig. 2a–d. A comparison of the energy densities of the analysed electrochemical cell type is presented in Fig. 2a. The NMC technology exhibits the highest energy density, being nearly50% higher than LFP and approximately six times higher than lead–acid technology. LTO chemistry exhibits a median energy density of 86 Wh/kg, which is approximately half that of LFP. Nevertheless, in stationary energy storage applications, energy density is frequently a factor of secondary importance.



(a)



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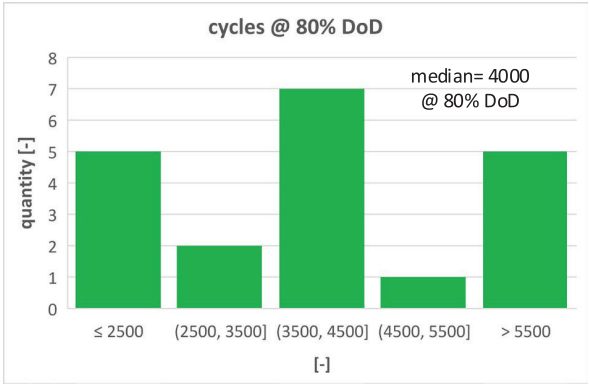

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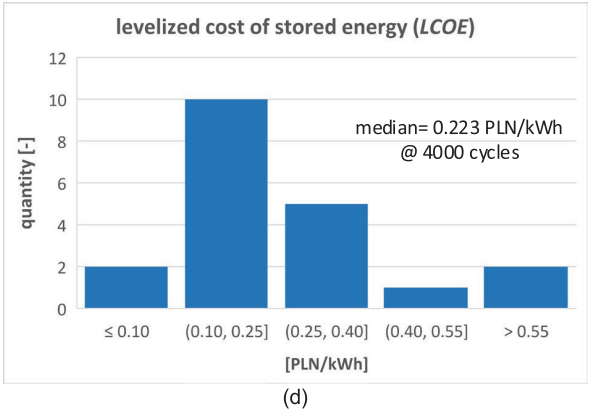


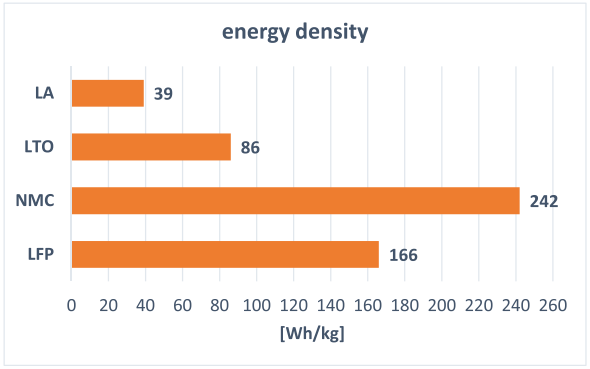
(d)

Fig. 1. Histograms for LFP cell type: (a) energy density; (b) installed energy cost *IEC*; (c) cycles; (d) levelized cost of stored energy *LCOE*

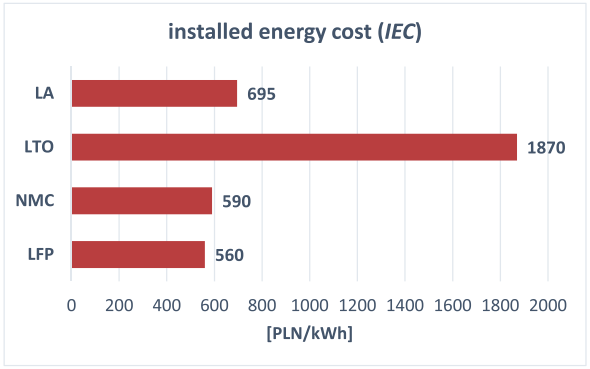
Comparison of the installed energy costs (*IEC)* of the investigated technologies in Fig. 2b indicates that LFP and NMC cells offer comparable costs for investors. Lead–acid technology, which remains popular among UPS suppliers, is approximately 20% more expensive than LFP. Nevertheless, the need for a BMS in LFP systems increases the overall cost of the energy storage system. The installed energy cost of LTO technology is significantly higher than that of the other technologies. However, as will be demonstrated later in this paper, it seems to be the most expensive, but it is not entirely true. This criterion does not consider the cyclic lifetime and the highest investment cost of energy storage using LTO type can be compensated by its superior cycle life. The median cycle life of LTO chemistry reaches 20 000 cycles, whereas the corresponding value for LFP is 4 000 cycles (Fig. 2c.). The cycle lifetimes of NMC and LA technologies are shorter than that of LFP, with median values of 2 000 and below 1 000 cycles, respectively. Therefore, the resulting levelized cost of stored energy (*LCOE*), presented in Fig. 2d is the lowest for LTO type. *LCOE* attains its highest value for lead–acid technology, nearly eight times greater than the lowest value, observed for LTO. As noted earlier, although LTO exhibits a higher installed energy cost, its superior cycle life yields the lowest cost per kilowatt-hour, estimated at 0.109 PLN/kWh. The second most economically favourable technology– LFP, exhibits a *LCOE* nearly double that of LTO. However, the low installed energy cost of LFP might justify its dominance in the present market. With a median *LCOE* of approximately 0.4 PLN/kWh, NMC technology is not favoured for stationary energy storage applications, except when power density is considered.

Summary and conclusions

This article compares four electrochemical cell and battery types: LFP, NMC, LTO, and lead-acid, in terms of their application in stationary storage systems, which are considered to be in continuous operation. The comparison criteria were obtained by processing many cell data published by manufacturers or sellers. The different cells were categorised according to their chemistry type and compared in terms of energy density, number of life-cycles, installed energy cost (*IEC*) and the proposed variant of levelized cost of energy (*LCOE*). The graphical representation of data showed some significant variations in cell parameters between manufacturers, even for the exact chemistry type; therefore, the median values were used to obtain



(a)



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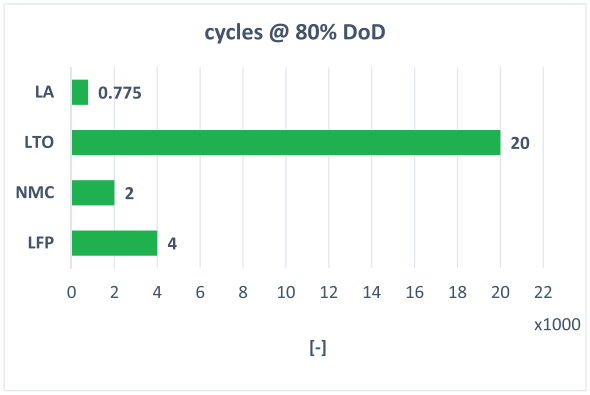

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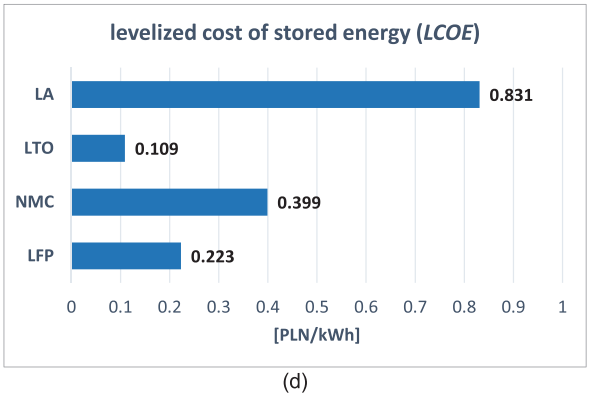

(d)

Fig. 2. Comparison of selected cell types under different conditions: (a) energy density; (b) installed energy cost *IEC*; (c) cycles; (d) levelized cost of stored energy *LCOE*

representative parameters and comparison criteria for each type.

The comparison of levelized energy cost value allowed for a reliable economic comparison of the cell types, which each has a different number of lifetime cycles and purchase cost. Moreover, the proposed variant of *LCOE* criterion led to the not obvious and not published conclusion that LTO cell type is significantly the cheapest, in terms of operation costs in the long-term perspective. The cheapest operation cost is related to the high number of life-time cycles. However, the installation cost of this cell type is three times higher than LFP type. This result justifies the wide usage of LFP type in stationary systems, which compromises installation and operation costs.

It should be highlighted that the presented value of operation costs (or levelized cost) does not include charging losses in cyclic operation; therefore, the real values will be higher if the lost energy price is considered. However, the relation between Li-ion chemistries might be similar and should not significantly affect the comparison results. The main aim of this analysis is to make a preliminary selection of cell types for cyclically used stationary battery systems. Therefore, the LTO or LFP type is the best choice depending on the priority of either the operation or the installation costs. The parameters might be different in a real system since the real operation conditions might differ from the nominal and affect the final choice of cell type.

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Appendix 1.

Table A1. Data collected from offers and the assessment criteria for LFP cells.

LFP cell's offer	Capacity [Ah]	Average voltage [V]	Cycle life-time [-]	Weight [kg]	Cost price [PLN]	Energy density [Wh/kg]	*IEC* [PLN/kWh]	*LCOE* [PLN/kWh]
LFP01	105	3.2	2500	2	210.00	168	625.00	0.347
LFP02	17	3.2	2000	0.48	127.60	113	2345.59	1.629
LFP03	105	3.2	4000	1.98	220.00	170	654.76	0.227
LFP04	280	3.2	6000	5.42	380.00	165	424.11	0.098
LFP05	230	3.2	6000	4.1	437.50	180	594.43	0.138
LFP06	100	3.2	4000	1.92	249.75	167	780.47	0.271
LFP07	50	3.2	4000	1.1	162.25	145	1014.06	0.352
LFP08	314	3.2	4125	5.4	425.00	186	422.97	0.142
LFP09	125	3.2	6000	3.1	197.83	129	494.57	0.114
LFP10	200	3.2	4000	5.6	683.00	114	1067.19	0.371
LFP11	202	3.2	4000	4.12	338.60	157	523.82	0.182
LFP12	100	3.2	4000	2.27	207.85	141	649.53	0.226
LFP13	530	3.2	6000	9.3	848.60	182	500.35	0.116
LFP14	40	3.2	2000	0.78	213.80	164	1670.31	1.160
LFP15	340	3.2	5500	5.49	456.53	198	419.61	0.106
LFP16	52	3.2	3000	1.1	157.83	151	948.50	0.439
LFP17	202	3.2	3500	4	307.54	162	475.77	0.189
LFP18	187	3.2	2500	3.47	237.79	172	397.37	0.221
LFP19	305	3.2	6000	5.55	229.29	176	234.93	0.054
LFP20	130	3.2	2000	2.34	176.16	178	423.47	0.294
median			**4000**			**166**	**559.13**	**0.223**
average			**4056**			**161**	**733.34**	**0.334**

Table A2. Data collected from offers and the assessment criteria for NMC cells.

NMC cell's offer	Capacity [Ah]	Average voltage [V]	Cycle life-time [-]	Weight [kg]	Cost price [PLN]	Energy density [Wh/kg]	*IEC* [PLN/kWh]	*LCOE* [PLN/kWh]
NMC01	141	3.7	2000	2.1	365.60	248	700.79	0.487
NMC02	116	3.7	2500	1.75	264.30	245	615.80	0.342
NMC03	196	3.7	3000	2.9	410.07	250	565.46	0.262
NMC04	60	3.7	1500	0.8	296.15	278	1334.01	1.235
NMC05	54	3.7	1500	0.9	210.20	222	1052.05	0.974
NMC06	73	3.7	2500	0.95	193.93	284	718.01	0.399
NMC07	51	3.7	2000	0.98	210.60	193	1116.06	0.775
NMC08	113	3.7	3000	2	238.95	209	571.51	0.265
NMC09	90	3.7	3000	1.45	217.13	230	652.05	0.302
NMC10	248	3.7	2000	3.7	505.00	248	550.35	0.382
NMC11	53	3.7	1500	0.82	98.00	239	499.75	0.463
NMC12	26	3.6	3000	0.56	58.40	167	623.93	0.289
NMC13	76	3.7	1000	0.98	115.20	287	409.67	0.569
NMC14	30	3.7	500	0.52	58.00	213	522.52	1.451
NMC15	45	3.65	2000	0.66	99.68	249	606.88	0.421
NMC16	114	3.74	1500	1.74	183.92	245	431.37	0.399
NMC17	100	3.65	1000	2.1	236.00	174	646.58	0.898
NMC18	180	3.7	2000	2.7	178.00	247	267.27	0.186
NMC19	50	3.65	3000	0.86	98.40	212	539.18	0.250
NMC20	117	3.65	2500	1.79	164.00	239	384.03	0.213
median			**2000**			**242**	**589.19**	**0.399**
average			**2050**			**234**	**640.36**	**0.528**

Table A3. Data collected from offers and the assessment criteria for LTO cells.

LTO cell's offer	Capacity [Ah]	Average voltage [V]	Cycle life-time [-]	Weight [kg]	Cost price [PLN]	Energy density [Wh/kg]	*IEC* [PLN/kWh]	*LCOE* [PLN/kWh]
LTO01	20	2.3	60000	0.53	44.50	87	967.39	0.022
LTO02	10	2.4	100000	0.29	50.36	83	2098.33	0.029
LTO03	20	2.3	18000	0.52	170.90	88	3715.22	0.287
LTO04	40	2.4	20000	1.05	231.00	91	2406.25	0.167
LTO05	22	2.3	20000	0.52	102.08	97	2017.39	0.140
LTO06	45	2.3	25000	1.2	149.10	86	1440.58	0.080
LTO07	30	2.3	20000	0.71	133.93	97	1940.94	0.135
LTO08	30	2.3	12000	0.86	92.93	80	1346.86	0.156
LTO09	30	2.3	25000	1.01	84.00	68	1217.39	0.068
LTO10	55	2.3	25000	2	227.80	63	1800.79	0.100
LTO11	40	2.3	30000	1.24	140.00	74	1521.74	0.070
LTO12	20	2.4	30000	0.52	72.00	92	1500.00	0.069
LTO13	70	2.3	20000	1.81	158.00	89	981.37	0.068
LTO14	28	2.4	30000	0.77	170.00	87	2529.76	0.117
LTO15	65	2.2	20000	1.81	174.88	79	1222.94	0.085
LTO16	30	2.3	16000	1.03	135.60	67	1965.22	0.171
LTO17	110	2.3	25000	3	572.00	84	2260.87	0.126
LTO18	14	2.2	20000	0.35	70.40	88	2285.71	0.159
LTO19	25	2.3	20000	0.9	79.60	64	1384.35	0.096
LTO20	23	2.3	18000	0.55	145.00	96	2741.02	0.211
median			**20000**			**87**	**1870.87**	**0.109**
average			**27700**			**83**	**1867.21**	**0.118**

Table A4. Data collected from offers and the assessment criteria for LA cells.

LA cell's offer	Capacity [Ah]	Average voltage [V]	Cycle life-time [-]	Weight [kg]	Cost price [PLN]	Energy density [Wh/kg]	*IEC* [PLN/kWh]	*LCOE* [PLN/kWh]
LA01	265	12	500	75	4659.00	42	1465.09	4.070
LA02	160	12	700	55	3629.00	35	1890.10	3.750
LA03	200	12	1500	68	5369.00	35	2237.08	2.071
LA04	100	12	400	32	1659.00	38	1382.50	4.800
LA05	75	12	900	26.5	2319.00	34	2576.67	3.976
LA06	165	12	400	47	2959.00	42	1494.44	5.189
LA07	200	12	600	52	1545.19	46	643.83	1.490
LA08	100	12	2150	30	1420.00	40	1183.33	0.764
LA09	1200	2	1500	82	1800.00	29	750.00	0.694
LA10	310	6	700	46.6	628.24	40	337.76	0.670
LA11	3000	2	2100	170	2720.00	35	453.33	0.300
LA12	250	12	350	70	792.00	43	264.00	1.048
LA13	250	12	750	71.3	815.48	42	271.83	0.503
LA14	200	12	750	54	607.20	44	253.00	0.469
LA15	1200	2	2200	63.9	1134.20	38	472.58	0.298
LA16	1200	2	1500	82	1800.00	29	750.00	0.694
LA17	110	12	400	32	1198.50	41	907.95	3.153
LA18	3000	2	2200	140	3300.00	43	550.00	0.347
LA19	600	2	800	45	620.00	27	516.67	0.897
LA20	500	2	2100	36.6	488.00	27	488.00	0.323
median			**775**			**39**	**696.91**	**0.831**
average			**1125**			**38**	**944.41**	**1.775**

REFERENCES

[1] Nikolaidis P., Poullikkas A., A comparative review of electrical energy storage systems for better sustainability, Journal of Power Technologies, 97 (2017), No 3, 220–245

[2] Zakeri B., Syri S., Electrical energy storage systems: A comparative life cycle cost analysis, Renewable and Sustainable Energy Reviews, 42 (2015), 569–596

[3] Mzyk K., Possibilities of energy storage in residential photovoltaic installations – Overview, Archives of Thermodynamics, 45 (2024), No 2, 213–230

[4] Ceran B., A comparative analysis of energy storage technologies, Energy Policy Journal, 21 (2018), No 3, 97–110

[5] Komarnicki P., Energy storage systems: power grid and energy market use cases, Archives of Electrical Engineering, 65 (2016), No 3, 495–511

[6] Frączek S., Klaszczyk W., Stacherski A., Łęk A., Żołądek M., Selection of cells and analysis of the energy storage system for a solar car, Energy Policy Journal, 27 (2024), No 2, 47–70

[7] Wieczorek M., Lewandowski M., Jefimowski W., Cost comparison of different configurations of a hybrid energy storage system with battery-only and supercapacitor-only storage in an electric city bus, Bulletin of the Polish Academy of Sciences, 67 (2019), No 6, 1095–1106

[8] Gałuszkiewicz P., Gałuszkiewicz Z., Energy storage in electrochemical storage based on LiFePO4 and LTO batteries, Przegląd Elektrotechniczny, 4 (2024), 201–204 (in Polish)

[9] Jarnut M., Wermiński S., Waśkowicz B., Comparative analysis of selected energy storage technologies for prosumer-owned microgrids, Renewable and Sustainable Energy Reviews, 74 (2017), 925–937

[10] Pawel I., The cost of storage – how to calculate the levelized cost of stored energy (LCOE) and applications to renewable energy generation, Energy Procedia, 46 (2014), 68–77

[11] Obi M, Jensen S.M., Ferris J.B., Bass R.B., Calculation of levelized costs of electricity for various electrical energy storage systems, Renewable and Sustainable Energy Reviews, 67 (2017), 908–920

[12] Al_Issa H.A., Qawaqzeh M., Hussienat L.H., Oksenych R., Miroshnyk O., Moroz O., Trunova I., Paziy V, Halko S., Shchur T., Comparative analysis of lithium-iron-phosphate and sodium-ion energy storage devices, Informatics, Control, Measurement in Economy and Environmental Protection, 15 (2025), No 1, 49–54

[13] Omar N., Monema M.A., Firouz Y., Salminen J., Smekens J.,Hegazy O., Gaulous H., Mulder G., van den Bossche P., Coosemans T., van Mierlo J., Lithium iron phosphate based battery – Assessment of the aging parameters and development of cycle life model, Applied Energy, 113 (2014), 1575–1585

[14] Ecker M., Nieto N., Käbitz S., Schmalstieg J., Blanke H., Warnecke A., Sauer D.U., Calendar and cycle life study of Li(NiMnCo)O2-based 18650 lithiumion batteries, Journal of Power Sources, 248 (2014), 839–851