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Prospects for energy storage in the world and in Poland in the 2030 horizon

ABSTRACT: The second decade of the 21st century is a period of intense development of various types of energy storage other than pumped-storage hydroelectricity. Battery and thermal storage systems are particularly rapidly developing ones. The observed phenomenon is a result of a key megatrend, i.e. the development of intermittent renewable energy sources (IRES) (wind power, photovoltaics). The development of RES, mainly in the form of distributed generation, combined with the dynamic development of electric mobility, results in the need to stabilize the grid frequency and voltage and calls for new solutions in order to ensure the security of energy supplies. High maturity, appropriate technical parameters, and increasingly better economic parameters of lithium battery technology (including lithium-ion batteries) result in a rapid increase of the installed capacity of this type of energy storage. The abovementioned phenomena helped to raise the question about the prospects for the development of electricity storage in the world and in Poland in the 2030 horizon. The estimated worldwide battery energy storage capacity in 2030 is ca. 51.1 GW, while in the case of Poland it is approximately 410.6 MW.

KEYWORDS: electricity storage, lithium-ion batteries, megatrends in power industry, Polish storage market

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Introduction

For many years, pumped-storage hydroelectricity (PSH) has been the dominant energy storage technology worldwide. Although the current capacity of non-pumped storage hydroelectricity is relatively small (approx. 6.0 GW at the end of the year 2017), a rapid increase in this area (from 1.9 GW in the year 2010) allows to expect that the second decade of the 21st century will be a historic period from the point of view of energy storage development. The above trends from result a large number of available and developed technologies, growing market maturity, and improving storage economics.

The fastest developing technology (CAGR* for 2010–2017 at 30%) is storage electrochemical which allows for large-scale and high-efficiency storage of electricity, which until recently was considered to be the Holy Grail of the power industry. The dynamic development of electrochemical technologies translates into their significant share (29%) in the total installed energy storage capacity at the end of 2017.

Other rapidly growing technologies are based on thermal processes, while special attention should be paid to the molten salt technology. The average growth rate of thermal technologies is 26% (CAGR 2010–2017), while their share in the global installed energy storage capacity is approx. 47%.

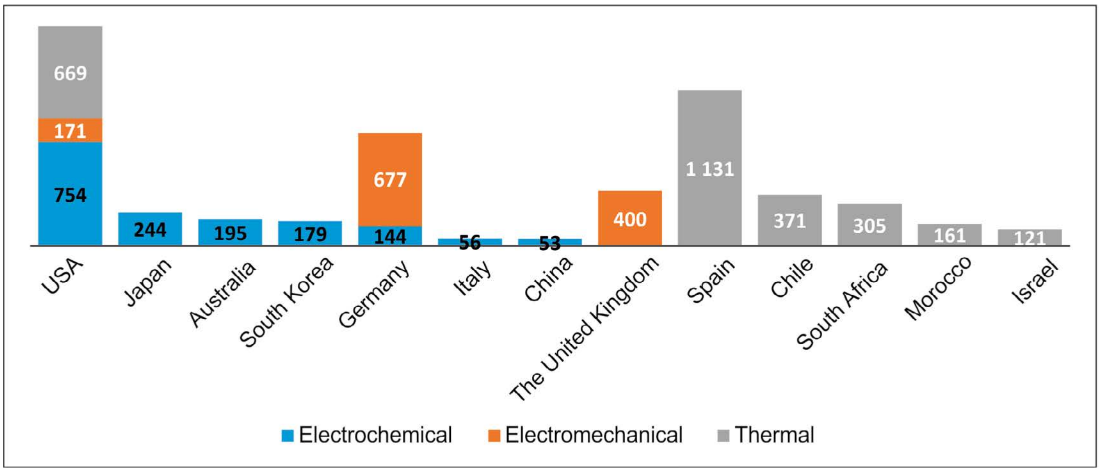

Fig. 1. The installed capacity of energy storage (non-PSH) at the end of 2017 [MW]
Source: U.S. DOE 2018

Rys. 1. Moc magazynów energii (non-ESP) w ujęciu geograficznym na koniec roku 2017 [MW]

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* Compound annual growth rate (CAGR) – is a measure of a mean growth rate over a time period. See e.g. www.investopedia.com/terms/c/cagr.asp or http://gieldowyradar.pl/sredniorocza-skladana-stopa-zwrotu/.

In the case of electromechanical technologies, a relatively large share (22%) can be observed; however, it should be noted that this results from the development that took place before 2010. This issue is discussed later in the article.

The last two groups of new technologies, i.e. chemical and electrical energy storage, are considered to be at a relatively early stage of development, without large volumes of installed capacity.

In the years 2010–2017, the PSH technology grew at a rate of 2% (CAGR).

From the geographical point of view, the leading countries in the development of non-conventional forms of energy storage are the United States, Germany and Spain (Fig. 1).

1. Megatrends determining the development of energy storage

The observed development in the field of energy storage raises questions about the reasons for this situation. An analysis of global megatrends in the power industry allow for determining the key factors of the discussed phenomenon, including:

- Rapid development of renewable energy sources (RES), particularly wind power and solar power (Fig. 2), whose generation, dependent on weather conditions, is characterized by intermittency and variability;
- Development of the so-called electric mobility leading to an increase in the number of vehicles with electric drive (Fig. 3);

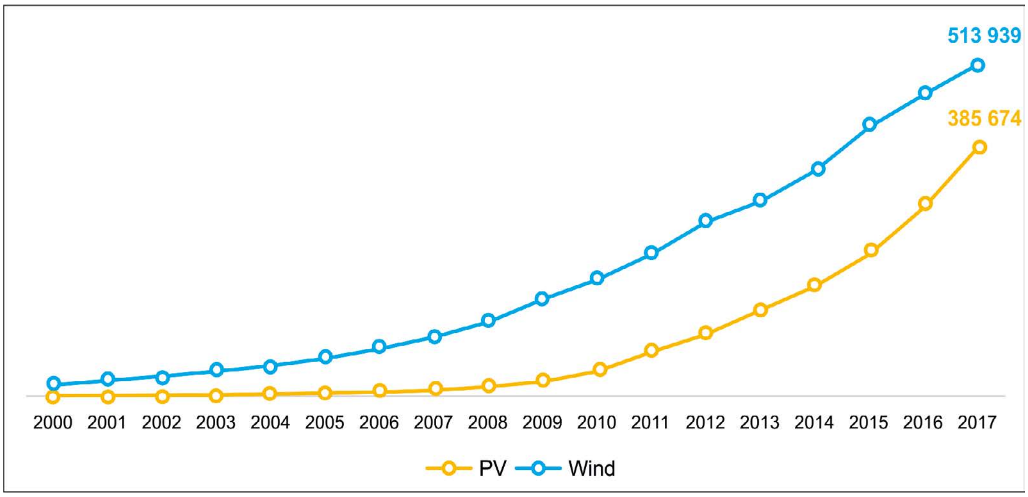
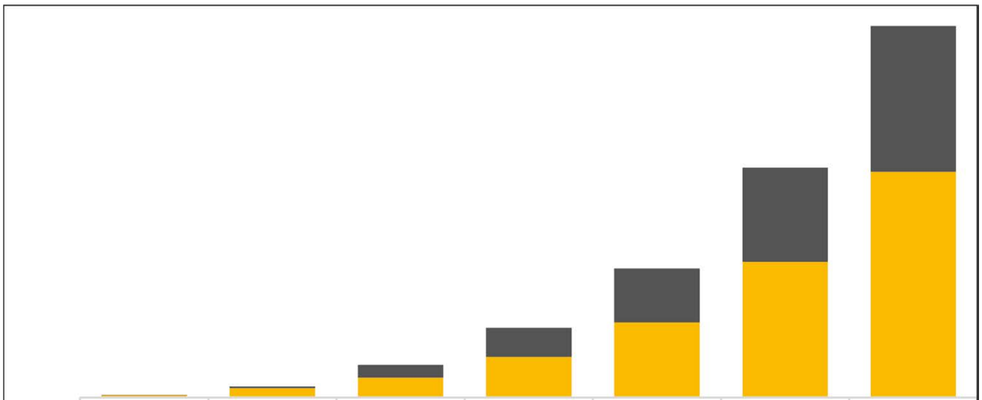


Fig. 2. The global installed capacity of wind and photovoltaic (PV) sources at the end of 2017 [MWe]
Source: IRENA 2018

Rys. 2. Globalna moc zainstalowana źródeł wiatrowych i fotowoltaicznych (PV) na koniec roku 2017 [MWe]



	2010	2011	2012	2013	2014	2015	2016
PHEV	0.4	9.3	70.0	161.6	295.7	517.1	795.1
BEV	12.1	51.3	109.3	221.5	411.1	739.8	1 235.4

Fig. 3. The number of electric cars worldwide [thousand]
PHEV (*plug-in hybrid electric vehicle*) – hybrid vehicles (internal combustion and electric) with the possibility of charging from the power network
BEV (*battery electric vehicle*) – vehicles with fully electric drive (battery-powered)
Source: IEA 2017

Rys. 3. Liczba samochodów elektrycznych na świecie [tys. szt.]
PHEV (ang. *plug-in hybrid electric vehicle*) – pojazdy o napędzie hybrydowym (spalinowo-elektrycznym) z możliwością ładowania z sieci elektroenergetycznej
BEV (ang. *battery electric vehicle*) – pojazdy o napędzie w pełni elektrycznym (zasilane bateriami)

- The need to develop the power grid (increase the flexibility in the light of increasing variability of use and production) so as to enable the integration of renewable energy sources and the supply of electric vehicles while maintaining appropriate energy parameters.

It is worth noting that the above trends, being the result of the energy revolution and part of the so-called Revolution 4.0, are indicators of the new model of the power industry, in which the security of supplies will be more dependent on renewable energy, storage, and the power grid rather than on fossil fuels and conventional thermal sources.

2. Energy storage technologies and their maturity

As mentioned in the introduction, the worldwide development of non-PSH technologies is based on numerous technologies that are at different stages of maturity. Despite the fact that most of the technologies are at their initial stages, some of them are already mature enough to become the driving force behind the trends described above.

The most developed and most widely used electromechanical technology is the pumped storage hydroelectricity; the total number of pumped-storage hydroelectric power stations in the world is 344 (with a total capacity of 180.5 GW), and the technology has been used since early 20th century. Compressed Air Energy Storage (CAES) can be considered technically advanced (installations operating for over 25 years), but the discussed technology is not much widespread (limited to several installations), of which the largest are Huntorf in Germany (290 MW, 1978) and McIntosh in the US (110 MW, 1991). Flywheels, the third type of electromechanical technology, used since the 1990's, are operated in 41 installations. This allows to consider them as a relatively mature technology.

Over the last decade, thermal and electrochemical energy storage have been the fastest developing technologies. In the case of thermal technologies, the leading technology is molten salt technology. When it comes to electrochemical technologies, the most mature ones are: lead-acid, lithium, nickel, and sodium-sulfur batteries, of which lithium batteries are the most dynamically developing – both in terms of the increase in storage capacity and in terms of reducing installation cost. Other promising technologies, currently less advanced and requiring further development, are metal-air batteries (due to net high energy density) and graphene batteries.

Detailed numerical data on the installed capacity of individual storage technologies is presented in Table 1.

TABLE 1. Energy storage technologies – the installed capacity at the end of the year 2017 [MW]

TABELA 1. Technologie magazynowania energii – moc zainstalowana na koniec roku 2017 [MW]

Method of energy storage	Technology	Capacity [MW]
Electromechanical	Pumped-hydro storage (PHS)	169 557
Thermal power stations	Molten salt	2 402
Electrochemical	Lithium batteries	1 412
Electromechanical	Flywheels	931
Thermal	Other	406
Electromechanical	Compressed-Air Energy Storage (CAES)	400
Electrochemical	Sodium-sulfur batteries (NaS)	189
Electrochemical	Lead-acid batteries	60
Electrochemical	Flow batteries	42
Electrochemical	Nickel batteries	30
Chemical	Hydrogen storage	17
N.A.	N.A.	78
N.A.	N.A.	175 525

Source: own work based on US DOE 2018.

Chemical and electrical technologies are at early stages of development. In the case of the former, however, there are more and more demonstration installations (approx. 60 in Europe alone, according to data from the European Power to Gas Platform), while the technologies based on superconductivity (SMES) and supercapacitors require further research and development.

The storage technologies from the point of view of the degree of maturity, technological risk, and investment outlays are presented in Fig. 4.

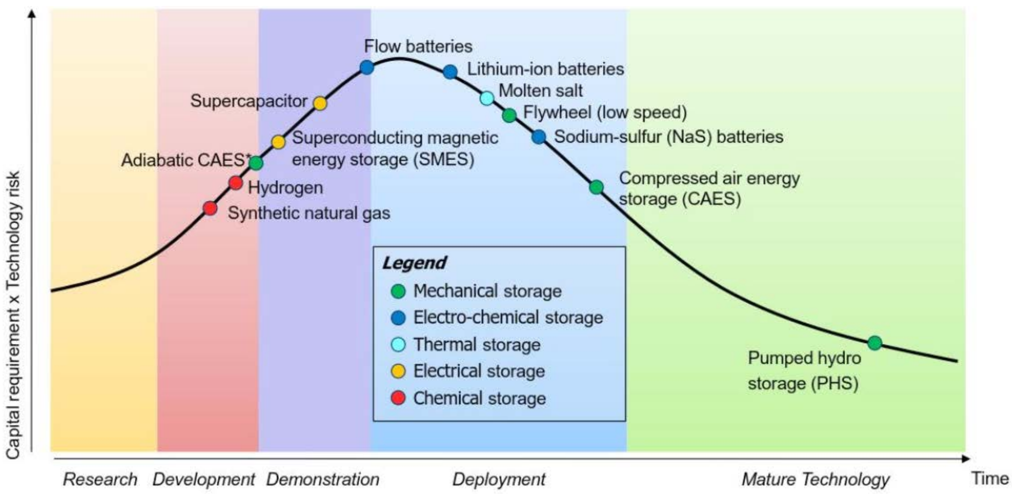


Fig. 4. The development curve of storage technologies
Source: Christiansen and Murray 2015

Rys. 4. Poglądowe pozycjonowanie technologii magazynowania na krzywej rozwoju

3. The impact of storage technology on grid operation

When discussing energy storage technologies, it is impossible not to mention their impact on the power grid. Taking into consideration the different states of the grid at various planning and co-ordination intervals and thus different needs associated with system balancing the following areas of application of storage technologies can be determined:

- Adjustment of frequency, power, and voltage;
- Ensuring an adequate level of capacity reserve in the medium and long term;

- Regular or occasional smoothing of the load curve of the system (shaving demand peaks and optimizing the operating parameters of thermal power stations during off-peak hours);
- Regular or occasional smoothing of intermittent generation of renewable energy sources (especially wind and solar);
- The reduction of grid losses due to the transmission of electrical power over great distances
- The possibility of restoring the system in case of a blackout.

The variety of storage technologies and their expected further development result in the possibility of choosing appropriate technical and economic solutions for the purpose of managing the power grid. The classification of storage technologies in terms of their suitability for the management of the system operation and in terms of their efficiency is shown in Fig. 5.

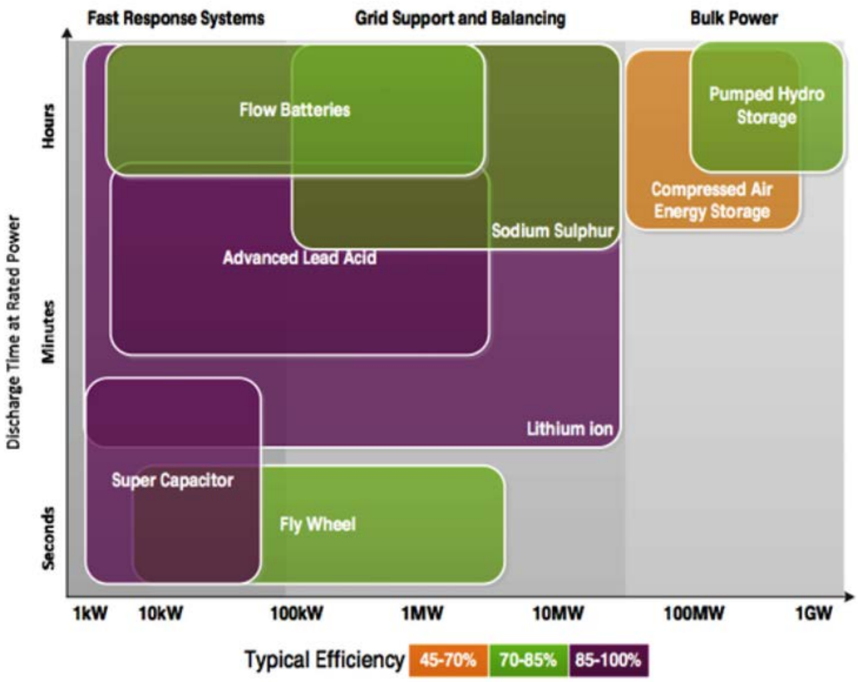


Fig. 5. Storage technologies from the point of view of efficiency, capacity, response time, and discharge time
Source: CleanTechnica 2015

Rys. 5. Technologie magazynowania z punktu widzenia sprawności, mocy, szybkości reakcji i czasu oddawania energii

An example of the use of lithium battery energy storage for adjusting the frequency and smoothing the production curve is presented in Figs. 6 and 7. The data applies to the Venteea wind farm in France using a 2.0 MW/1.3 MWh battery system.

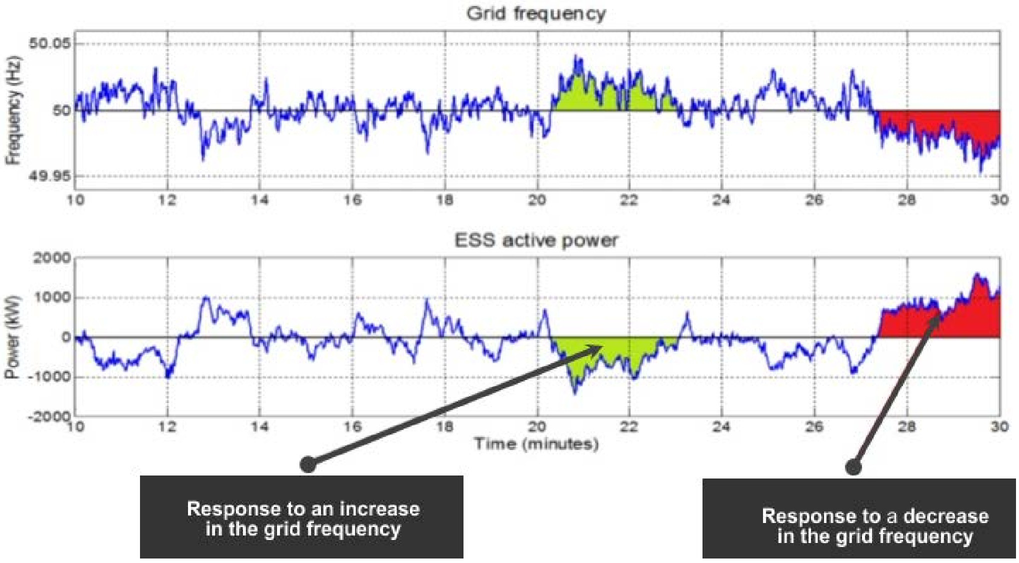


Fig. 6. Adjusting the grid frequency using lithium-ion battery energy storage
Source: Schneider Electric 2018

Rys. 6. Regulacja częstotliwości sieci z wykorzystaniem magazynu energii (baterie litowo-jonowe)

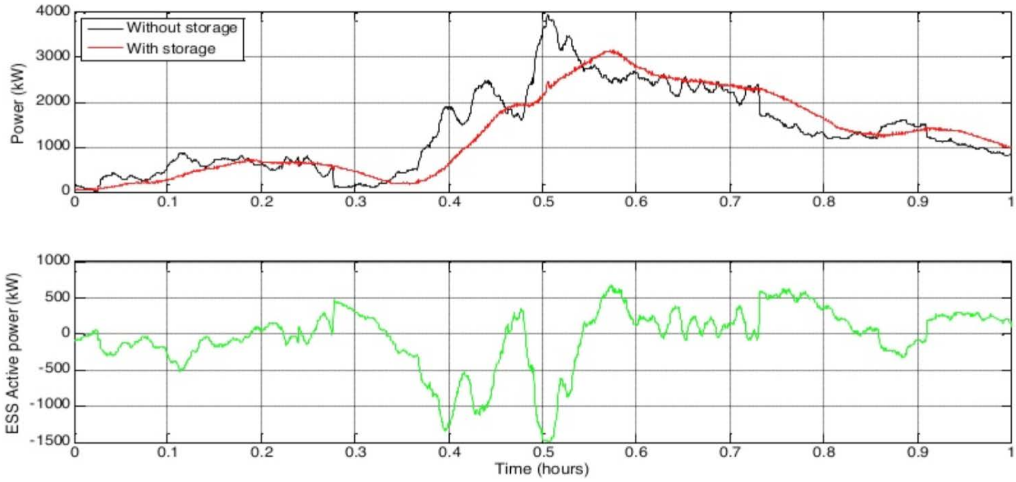


Fig. 7. Smoothing the production curve of a wind farm by using lithium-ion battery energy storage
Source: Schneider Electric 2018

Rys. 7. Wygładzanie krzywej produkcji farmy wiatrowej z wykorzystaniem magazynu energii (baterie litowo-jonowe)

4. Lithium batteries as the driving force behind the current stage of development of energy storage

As mentioned above, the current decade is a period of intensive development of energy storage based on lithium, and especially lithium-ion (Li-Ion), batteries, which represent approx. 85% of the total capacity of 1.4 GW installed at the end of 2017 (see Table 1). To explain the reasons behind this phenomenon, it is worth analyzing this form of storage from both the technical and economic point of view.

The main advantages of lithium-ion batteries are high energy density, long life (determined by the number of charge/discharge cycles), and high efficiency. When discussing the advantages of Li-Ion batteries, it is impossible not to mention the weaknesses of this technology. From a technical point of view, the most important issues are connected with the charging process, and safety concerns (the risk of explosion due to overheating and/or the use of low quality materials). From an economic point of view, the attractiveness of a lithium-ion battery storage system is based on the cost of the battery itself (materials for the construction of the anode and cathode, separator, and electrolyte), software for managing the installation, including BMS (battery management system), the costs of power conversion, and systems to provide security and cooperation with the power grid. The cost structure of a lithium-ion battery energy storage system installation is presented in Fig. 8.

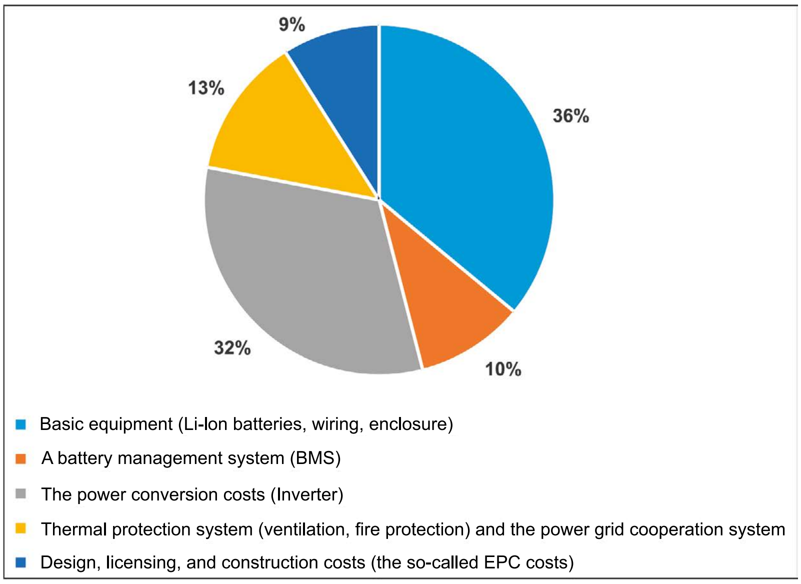


Fig. 8. The cost structure of an energy storage system installation [%]
Source: own work based on Lazard 2017 and PacifiCorp 2016

Rys. 8. Poglądowa struktura kosztu instalacji systemu magazynowania energii [%]

Analyzing economic issues, it is worth noting that in the long term the cost of lithium-ion batteries has dropped significantly (Fig. 9), while current forecasts indicate the possibility of reaching a level below USD 200/kWh in 2019 (Kittner et al. 2017) and USD 100/kWh in the period between 2020 and 2025 (Chediak 2018).

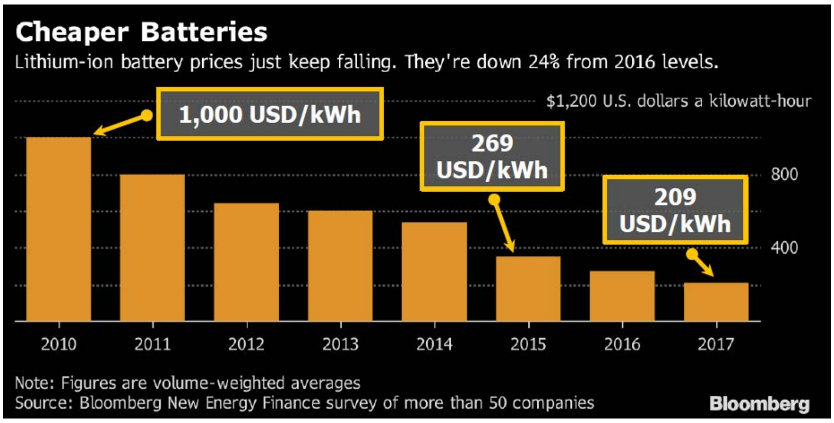


Fig. 9. The cost trajectory for lithium-ion batteries (the so-called battery pack)
Source: own work based on Chediak 2018

Rys. 9. Trajektoria kosztu baterii litowo-jonowych (tzw. *battery pack*)

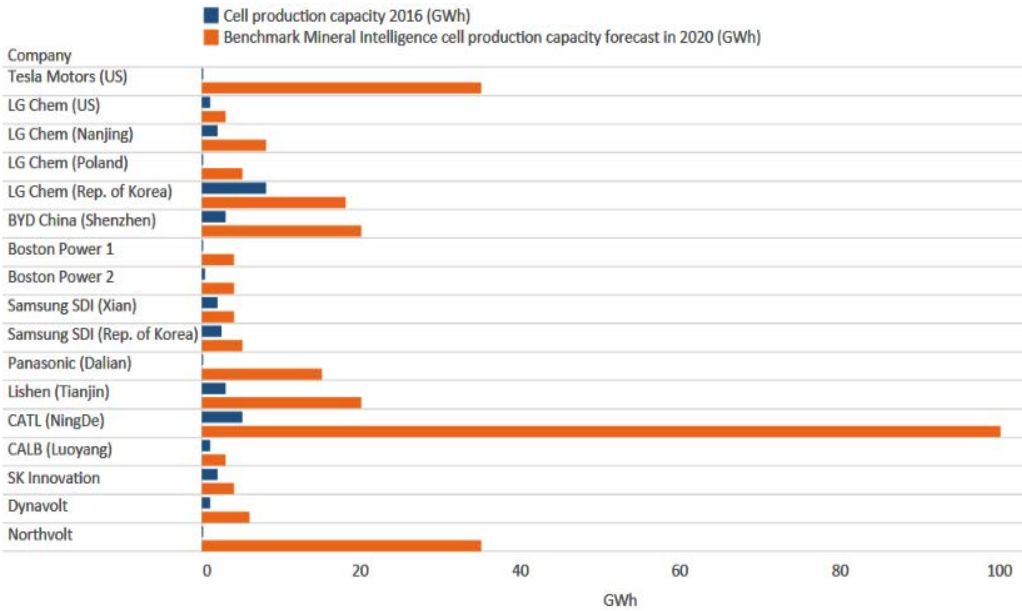


Fig. 10. Production capacity forecast for producers of lithium-ion batteries
Source: IRENA 2017

Rys. 10. Prognoza rozwoju mocy produkcyjnych producentów baterii litowo-jonowych

The above phenomenon of a rapid decrease in the cost of Li-Ion batteries results primarily from the competition between manufacturers and from the optimization of production processes. The scale of competition and the pace of development of production of lithium-ion batteries is well illustrated in Fig. 10, which presents the forecasted increase of manufacturing capacity from approximately 28 GWh/year to approx. 174 GWh/year (an increase by 521%).

5. Energy storage in Poland

Global megatrends in the development of electric energy storage are becoming noticeable also in Poland. While the pumped storage hydroelectricity is the dominant technology (1.706 MW), is it is worth noting that some Polish Distribution Network Operators (DNOs) already operate Li-Ion battery energy storage systems (Table 2), which can be considered pioneer installations.

When discussing the development of energy storage, it should be noted that the above mentioned installations are not only the domain of DNOs, but can also be an important element of the distributed generation and local supply systems (households, industry). Taking the rapid

Table 2. Energy storage installations using lithium-ion technology in Poland used by DNOs

Tabela 2. Instalacje magazynowania energii elektrycznej w technologii litowo-jonowej w Polsce wykorzystywane przez OSD

DNO	Description of the installation
Energa	✦ 0.75 MW/1.5 MWh, Puck, commissioned in September 2016 ✦ 6.0 MW/27,0 MWh, the Gdańsk area, to be commissioned in 2019
The innogy Group	✦ 36.0 kWh, Warsaw, commissioned in Q4 2016

Source: own work.

Table 3. Photovoltaic installations in Poland as determinants of the development of energy storage

Tabela 3. Instalacje fotowoltaiczne w Polsce jako determinanta rozwoju magazynowania

	2013	2014	2015	2016	2017
Capacity [MWe]	2	25	100	199	273
The number of micro-installations [thousand]	N.A.	0.9	4.2	17.1	27.3

Source: own study based on Curkowski et al. 2017; GlobEnergia 2018; GwZ 2017; ERO 2018.

development of photovoltaic systems in Poland in the years 2013–2017 (Table 3) into account, it can be expected that this trend will be a key determining factor for the development of small scale storage systems.

6. Estimation of potential for the development of lithium battery energy storage systems

The factors described above, related to the development of electricity storage, raise a question about the scale of the phenomenon in the future. In order to estimate the trajectory of the increase in installed capacity of energy storage systems in Poland and worldwide, it was assumed that the declining cost of batteries and the increasing installed capacity of intermittent renewable energy sources (wind, photovoltaic) will continue to be the key factors determining further development. The above assumptions were adopted based on the strong correlation between the above mentioned parameters (Table 4).

TABLE 4. The correlation between the capacity of Li-Ion battery energy storage systems and selected drivers

TABELA 4. Korelacja pomiędzy mocą magazynów Li-Ion a wybranymi czynnikami

Factors	Correlation
The capacity of energy storage systems worldwide – Battery cost	–90%
The capacity of energy storage systems worldwide – The total installed capacity in PV sources	+98%
The capacity of energy storage systems worldwide – The total installed capacity in wind sources	+96%

Source: own work.

The next step in estimating the installed capacity of Li-Ion energy storage systems was the development of a regression model, where the described variable was the global installed capacity of storage systems, while describing variables included the battery cost, global installed capacity of wind power, and global installed capacity of PV. The target values of the describing variables for the year 2030 were adopted as in Table 5.

On the basis of the model constructed as above, the development path of Li-Ion battery energy storage systems in the world was estimated until 2030 (Fig. 11). Then, the installed capacity

TABLE 5. The target values of the describing variables (2030)

TABELA 5. Docelowe wartości zmiennych opisujących (rok 2030)

Variable	Unit	Value	Source
Battery cost	USD/kWh	99	Krupa and Kamiński 2017
The global installed capacity of PV sources	GWe	1.760	IRENA 2016
The global installed capacity of wind sources	GWe	2.110	GWEC 2016
The capacity installed in PV sources in Poland	MWe	9.500	Own work
The installed capacity of wind sources in Poland	GWe	12.000	PEP 2050

Source: own work.

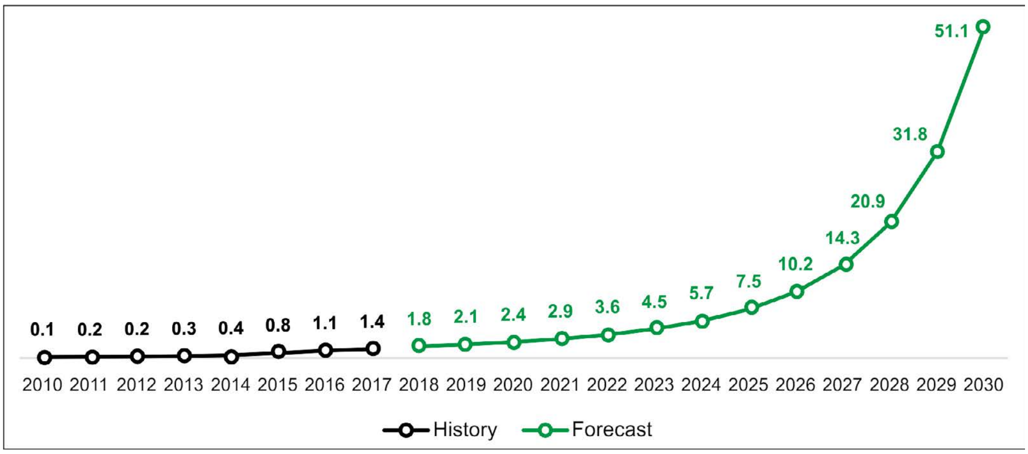


Fig. 11. The historical and forecasted installed capacity of lithium-ion battery energy storage systems worldwide [GW]
Source: own work

Rys. 11. Historyczna i prognozowana moc zainstalowana magazynów energii elektrycznej w technologii litowo-jonowej na świecie [GW]

of a storage system per 1 MWe of RES capacity was estimated. This index was used for calculations for Poland, while the target values of the installed capacity in Polish wind and PV power plants were adopted as in Table 5. Finally, the trajectory of the installed capacity in domestic energy storage systems is presented in Fig. 12.

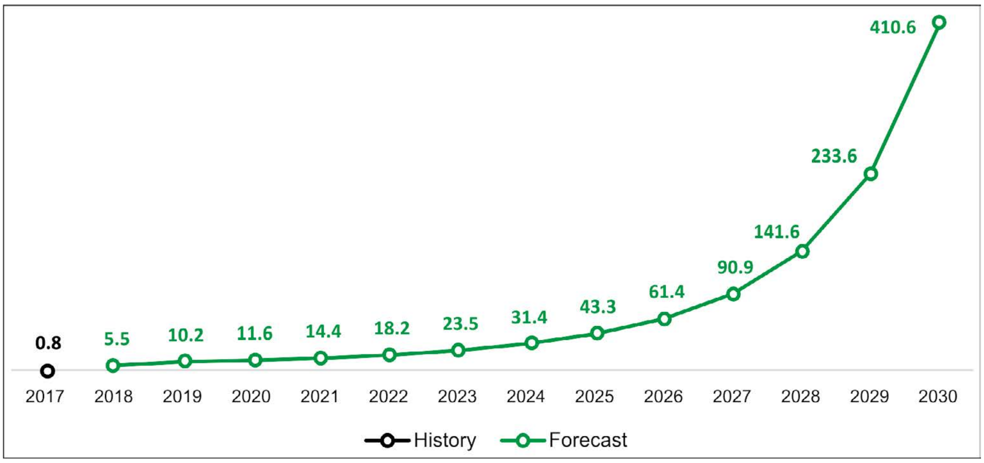


Fig. 12. The historical and forecasted installed capacity of lithium-ion battery energy storage systems in Poland [MW]
Source: own work

Rys. 12. Historyczna i prognozowana moc zainstalowana magazynów energii elektrycznej
w technologii litowo-jonowej w Polsce [MW]

Conclusions

Based on the characteristics and analysis of energy storage in the world and in Poland, the presented paper has shown that this area is at a relatively early stage of development. However, taking the key factors determining its development into account, a high demand for various forms of energy storage can be expected in the future.

Taking the initial stage of development of energy storage in Poland into account, attention should be paid to the lack of comprehensive analyses of the discussed phenomenon. In the context of the above, the presented forecast for the domestic market can be considered as one of the pioneering studies quantifying the potential size of the Polish market. In addition, it can serve as a starting point for further, more detailed studies.

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Perspektywy rozwoju magazynowania energii elektrycznej na świecie i w Polsce w horyzoncie roku 2030

Streszczenie

Druga dekada XXI wieku to okres intensywnego rozwoju magazynowania energii elektrycznej w formach innych niż elektrownie szczytowo-pompowe. Szczególnie szybko rozwijającym się segmentem magazynowania są technologie bateryjne oraz cieplne. Obserwowane zjawisko jest pochodną kluczowego megatrendu, tj. rozwoju odnawialnych źródeł energii (OZE) o nieciągłym charakterze pracy (wiatr, fotowoltaika). Rozwój OZE, przebiegający głównie w modelu rozproszonym, w połączeniu z dynamicznym rozwojem elektromobilności, skutkuje potrzebą stabilizacji parametrów sieci elektroenergetycznej (napięcie, częstotliwość) oraz wymusza podejmowanie nowych rozwiązań w celu zapewnienia bezpieczeństwa dostaw energii. Technologią znajdującą się w odpowiednim stadium dojrzałości, o odpowiednich parametrach technicznych oraz coraz lepszych parametrach ekonomicznych, są baterie litowe (w tym litowo-jonowe), co skutkuje szybkim wzrostem mocy zainstalowanej tego typu magazynów. Przytoczone powyżej zjawiska pozwoliły postawić pytanie o perspektywy rozwoju magazynowania energii elektrycznej na świecie i w Polsce w horyzoncie roku 2030. Oszacowana w niniejszym artykule globalna moc magazynów bateryjnych na świecie w roku 2030 to około 51,1 GW, podczas gdy analogiczna wartość dla Polski wynosi około 410,6 MW.

Słowa kluczowe: magazynowanie energii elektrycznej, baterie litowo-jonowe, megatrendy w energetyce, rynek magazynowania w Polsce