CINQ CONTINENTS
REVUE ROUMAINE DE GEOGRAPHIE

Volume 16 / Numéro 34
Hiver 2026
ISSN : 2247 - 2290
p. 161-182

Storage of electrical energy in batteries. Case study: Romania

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Citer ce document :

POPA, V. 2026. Storage of electrical energy in batteries. Case study: Romania. *Cinq Continents 16* (34): ?-??.

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Stocarea energiei electrice în baterii. Studiu de caz: România. Problemele de mediu asociate cu arderea combustibililor fosili, în special schimbările climatice, dar și perspectivele creșterii consumului de energie au condus la dezvoltarea accelerată a energiei regenerabile. În același timp, numeroase centrale electrice pe cărbune, responsabile pentru emisii semnificative de gaze cu efect de seră, au fost închise. Întrucât sursele regenerabile (solară, eoliană) sunt intermitente, iar cererea de energie electrică fluctuează pe parcursul zilei, au apărut dezechilibre majore în sistemele energetice. Pentru a rezolva aceste probleme, sistemele de stocare a energiei au fost considerate cea mai eficientă soluție. Această cercetare evidențiază necesitatea dezvoltării tehnologiilor de stocare a energiei electrice, exemplificând situația sistemului energetic din România. Aceasta prezintă problemele structurale ale sistemului energetic din România, apărute odată cu extinderea considerabilă a energiei regenerabile și închiderea unor centrale electrice pe cărbune, precum și măsurile luate pentru echilibrarea sistemului energetic și reducerea costurilor cu energia electrică. Deși capacitatea sistemelor de stocare a crescut semnificativ la nivel mondial în ultimii ani, acestea nu sunt complet lipsite de riscuri și provocări.

Cuvinte cheie: : energie regenerabilă, BESS, România, riscuri și provocări.

Storage of electrical energy in batteries. Case study: Romania. Environmental problems associated with the burning of fossil fuels, especially climate change, but also the prospects for increasing energy consumption have led to the accelerated development of renewable energy. At the same time, many coal-fired power plants, responsible for significant greenhouse gas emissions, have been closed. Since renewable sources (solar, wind) are intermittent and electricity demand fluctuates throughout the day, major imbalances have emerged in energy systems. To solve these problems, energy storage systems have been considered the most effective solution. This research highlights the need to develop electricity storage technologies, exemplifying the situation of the energy system in Romania. It shows the structural problems of the energy system in Romania, which arose with the considerable expansion of renewable energy and the closure of some coal-fired power plants, as well as the measures taken to balance the energy system and reduce electricity costs. Although the capacity of storage systems has increased significantly worldwide in recent years, they are not completely free from risks and challenges.

Keywords: renewable energy, BESS, Romania, risks and challenges.

1. INTRODUCTION

Global electricity consumption has increased significantly over time, driven by socio-economic development, and is expected to continue to increase. It is estimated that global energy demand will more than double by 2050 and more than triple by the end of the century (Guney, Tepe, 2017). Since the burning of fossil fuels for electricity generation is responsible for greenhouse gas emissions and other pollutants, renewable energy sources have increasingly been used. The most widely used renewable sources, such as photovoltaics and wind power, are intermittent. Solar panels can only be used during the day, when the weather is sunny, and wind turbines depend on the wind. Sometimes, renewable energy sources can produce excess energy, causing the system to be overloaded. In addition, there are fluctuations in electricity demand during the day. Therefore, to ensure an appropriate balance between energy generation and demand, energy storage systems are considered the most realistic and efficient choice (Guney, Tepe, 2017; Mitali et al., 2022; Xie et al., 2025).

Stationary energy storage systems are essential in various applications, such as: data centers, grid applications, renewable energy integration, telecommunications, emergency systems, industrial and manufacturing, commercial buildings, residential use, agriculture, remote and off-grid or aerospace and defense (BCI, 2026a).

In general, storing electrical energy requires converting it into another form of energy (Guney, Tepe, 2017). The implementation of energy storage systems began in the 19th century and has come a long way to reach the point where it is today. In 1839, Sir William Robert Grove invented the first simple fuel cell. He mixed hydrogen and oxygen in the presence of an electrolyte and produced electricity and water. In 1859, French physicist Gaston Planté invented the first practical version of a rechargeable battery based on lead-acid chemistry, and in 1991, Sony launched the first commercial lithium-ion battery (Mitali et al., 2022).

Several energy storage technologies have been developed: mechanical, chemical, electrochemical, electrical, thermal or hybrid (Dehghani-Sanij et al., 2019; Mitali et al., 2022). Among them, electrochemical storage systems (different types of batteries) are preferred due to their high efficiency, fast response and short construction times (May et al., 2018; Xie et al., 2025). Electrical energy must be converted into another form to be stored, and batteries are an obvious storage option (Dehghani-Sanij et al., 2019). In recent years, there has been an increase in the development and implementation of battery energy storage systems (BESS), especially those using lithium-ion batteries, due to their superior properties (Liu et al., 2020; Conzen et al., 2023). BESS plays an increasingly important role in decarbonizing transport through electrification, in the transition from traditional fuels to renewable energy sources, and in ensuring access to electricity for off-grid communities. Global demand for batteries is expected to grow by

25% per year, reaching approximately 2600 GWh in 2030. This could enable batteries to reduce carbon emissions from the transport and energy sectors by 30% (Hannan et al., 2021).

In the energy sector, BESS are essential for balancing/stabilizing power grids and maximizing the efficiency of renewable sources, such as photovoltaic panels and wind turbines. These systems capture energy during peak production or low consumption and release it when demand increases or renewable sources are not producing electricity. BESS also ensure power supply in the event of power outages or extreme weather events, are easy to install, and help reduce costs by charging batteries when the market price of energy is low or negative and discharging them when the price is high. BESS are probably the most effective method of stabilizing power grids that access significant amounts of renewable energy (Dehghani-Sanij et al., 2019).

BESS capacity can vary significantly, from about one megawatt-hour to several hundred megawatt-hours, and are designed to operate for one to over 4 hours. Standard, metal containerized systems, which represent a form of modular design, have become the most popular means of efficiently integrating BESS (Conzen et al., 2023). Batteries are composed of a number of cells, each with three basic components: two electrodes, namely an anode and a cathode, and an electrolyte. BESS are generally classified into four main types, based on their chemical composition and engineering design: lithium-ion batteries, sodium-based batteries, flow batteries, and lead-acid batteries (May et al., 2018).

Lithium-ion batteries are the most widely used technology due to their high energy density, charge/discharge efficiency, and long life. They are widely used in grid-scale and residential energy storage, renewable energy integration, electric vehicles, and data center backup power. Lithium-ion batteries are often classified and named based on the composition of the elements in their cathode (one of the two electrodes where lithium ions are stored during charge and discharge cycles). The most common chemical compositions are: lithium nickel manganese cobalt oxide, lithium nickel cobalt aluminum oxide, lithium iron phosphate, and lithium cobalt oxide. Although they have a lower energy density, lithium iron phosphate batteries are a variant that offers high thermal stability (fire-resistant), long life, lower cost, and does not use cobalt or nickel (IEA, 2024).

Flow batteries are rechargeable electrochemical energy storage systems that consist of two tanks containing liquid electrolytes pumped through one or more electrochemical cells. These cells can be connected in series or parallel to achieve the desired power capacity, while the tanks can be scaled to achieve the desired energy capacity. Their capacity increases with increasing the amount of electrolyte stored in the tanks. Flow batteries have an extended lifespan (over 20 years), many components can be recycled, and the electrolytes can be recovered and reused. Although there are several variants, based on electrolyte chemistry, the vanadium redox flow battery is currently the most commercially available and technologically mature (IEA, 2024; BCI, 2026b).

Sodium-ion batteries are an alternative to lithium, although they have a lower energy density, making them particularly attractive for stationary energy storage applications. Operating similarly to lithium-ion batteries but using a more abundant chemical element, these batteries have the potential to be produced more cheaply and with more reliable supply chains. These batteries perform better in extreme cold conditions, are less likely to overheat, and do not require cobalt or nickel (IEA, 2024; BCI, 2026c).

Lead-acid batteries are an old and inexpensive technology, used mainly in the automotive sector. Most industrial batteries are used for standby applications, to provide reliable power for telecommunications, data networks, national security and a wide range of applications where continuity of power supply is essential. They have a low capital cost (cheap manufacturing and widely available globally), high recyclability (recycling rate exceeds 99% through a mature infrastructure) (Table 1). Lead-acid batteries have been developed in recent years to have much longer cycle lives compared to two decades ago, given that the battery is not routinely returned to a fully charged state (May et al., 2018).

Table 1. Advantages and disadvantages of the main battery energy storage systems

BESS type	Advantages	Disadvantages
Lithium-ion batteries	- high energy density - long cycle life - high efficiency - fast charging & discharging - low maintenance	- fire risk & thermal runaway - higher cost - raw material constraints - degradation over time - end-of-life challenges
Lead-acid batteries	- low cost - proven and reliable - high surge power	- short cycle life - heavy and bulky - limited depth of discharge - environmental concerns (contains toxic lead and sulfuric acid)
Sodium-based batteries	- lower cost - enhanced safety - sustainability - good cycle life	- lower energy density - high operating temperatures - still developing
Flow batteries	- long cycle life - scalability - non-flammable - deep discharge capability	- lower energy density - high initial cost - lower efficiency

Source: EticaAG, 2026

2. METHODOLOGY

In the current climate context, the global energy system is oriented towards low-carbon sources, especially renewable sources. The research mainly analyzes the BESS situation in Romania. The data used in this research come exclusively from the specialized literature. Sources belonging to national and international institutions with concerns in the field were consulted, such as Transelectrica or the International Energy Agency, as well as specialized scientific articles and other sources that addressed the issue of energy storage systems. Quantitative and qualitative methods were used in the processing and interpretation of these data. In order to highlight the dynamics of some indicators (such as the evolution of battery storage capacity worldwide or the structure of the Romanian energy system), graphical methods were used, and the results were subsequently interpreted.

In the case of Romania, the relationship between the structure of the energy system, the development of renewable energy and the imbalances that arose after the abandonment of some fossil fuel power plants was investigated. In presenting the current situation of the energy system, data published mainly by Transelectrica, the national electricity transmission operator in Romania, were used. The identification of BESS in Romania was based on consulting materials published by companies with projects in the field or some media sources (such as Economica). The identification of various characteristics of the projects was also sought: installed power, BESS storage capacity or geographical location, data that were centralized in the form of a table. The identification of risks and challenges associated with BESS was also sought. In this regard, the specialized literature was consulted, with numerous scientific articles addressing such aspects.

3. RESULTS

3.1. Global situation

BESS is the fastest growing energy technology today. Over the past decade, global installed battery storage capacity has grown exponentially, from around 1 GW in 2013 to over 270 GW in 2025. In 2025, 108 GW of new battery storage capacity was deployed worldwide, 40% more than in 2024 (Figure 1). Installed capacity is now eleven times higher than in 2021 (IEA, 2024; IEA, 2026).

Lithium iron phosphate (LFP) batteries account for about 90% of deployments. Although they have a lower energy density than the chemistries commonly used in electric vehicle batteries, LFP batteries are typically cheaper, safer, and better suited to more frequent use cycles. Just five years ago, the market share of LFP batteries in deployments was well below 50% (IEA, 2026). LFP batteries are mostly produced in

China. Lithium-ion batteries remain a key part of short-term storage, but alternative chemistries are being developed to either compete with them or complement them (IEA, 2024).

About 80% of new battery capacity in 2025 was utility-scale, i.e. large applications connected directly to the transmission or distribution grid (front-of-the-meter), typically ranging from a few hundred kWh to several GWh. The remainder was capacity installed behind the meter (behind-the-meter) by commercial and residential consumers. Battery storage durations are gradually increasing (IEA, 2026). By 2025, average large-scale energy storage durations had reached around 2.5 hours globally, with some markets such as Chile and Saudi Arabia developing projects with durations exceeding 3-4 hours (Wood Mackenzie, 2026).

China continued to lead battery deployment in 2025, accounting for about 54% of global additions (up from about 20% in 2019), followed by the United States and Europe (most notably Germany, Italy and the United Kingdom). In China, a significant number of companies already have at least a few GW installed or are in advanced stages of development. About 74 of the top 100 battery storage developers globally are Chinese. In the US, most deployments have been in California, Texas and other southwestern states. However, deployment is expanding beyond the largest markets, with strong momentum in Australia (with a 55% increase in 2025) and parts of the Middle East (most notably Saudi Arabia). Globally, storage capacity is projected to reach 1,545 GW by 2034 (Wood Mackenzie, 2026; IEA, 2024).

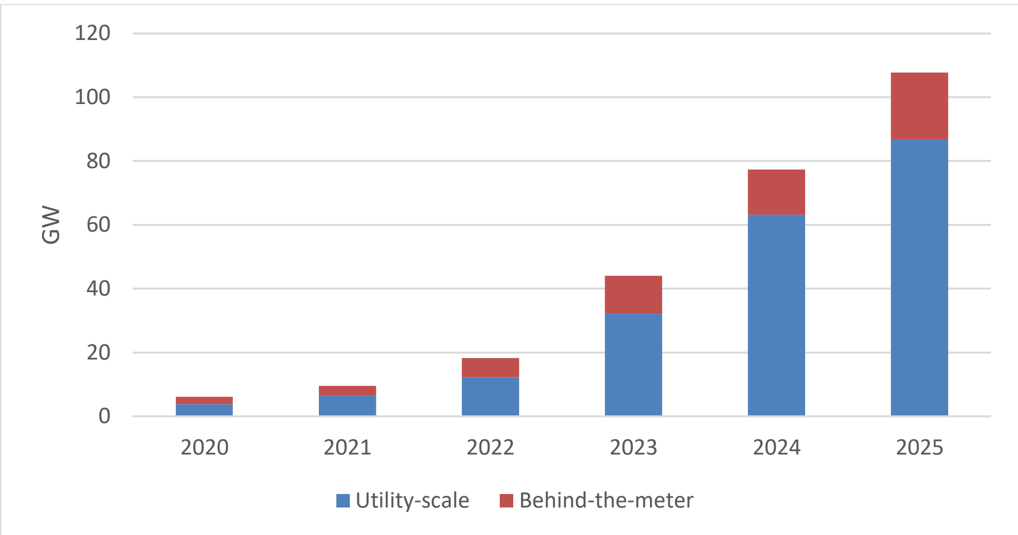

Figure 1. Global battery storage capacity additions, 2020-2025 (Source: IEA, 2026)

3.2. Romania's energy system and the need for battery storage systems

Romania has a diversified energy mix, with a profile dominated by low-carbon sources (around 66% of the total). Thus, in 2025, hydropower accounted for almost a quarter of the total gross energy produced (24%), while nuclear energy contributed 21% (Figure 2). As a result of the increase in installed power in wind and photovoltaic plants, around 12% of this type of energy was represented by wind energy and 5% by photovoltaic energy. The remaining 4% came from prosumers and storage facilities. In addition, around 34% of the total gross electricity production was generated by fossil fuels, of which 14% coal and 20% hydrocarbons (Transelectrica, 2026).

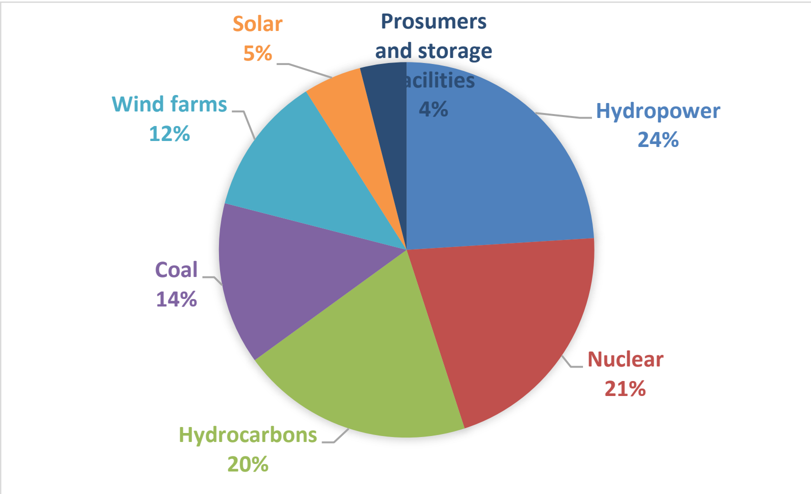

Figure 2. Gross electricity production in Romania, by type of producer, 2025
(Source: Transelectrica, 2026)

In recent years, power plants or generating units operating on coal or hydrocarbons with an installed capacity of 5,508 MW have been decommissioned (Ministry of Energy, 2024). In January 2026, the gross installed capacity in the national energy system totaled 19,368 MW, structured as follows: hydro (6,688 MW), wind (3,136 MW), photovoltaic (3,094 MW), hydrocarbons (2,802 MW), coal (2,095 MW), nuclear (1,413 MW), biomass (139 MW) (Transelectrica, 2026) (Figure 3).

Regarding renewable sources with variable production (wind, solar), their share in installed power was 32%. In January 2026, wind power plants had a gross installed power of 3,136 MW, i.e. 16.2% of the total, but their contribution to electricity production was 12%, due to variability. Moreover, if the installed power from solar sources was 3,094 MW, i.e. almost 16% of the total, their contribution to electricity production was only 5% (Transelectrica, 2026). In recent years, a sudden increase in the installed power of prosumers has been noted, from 478 MW at the beginning of 2023 to 3,400 MW in March 2026 (Ministry of Energy, 2024; APCE, 2026).

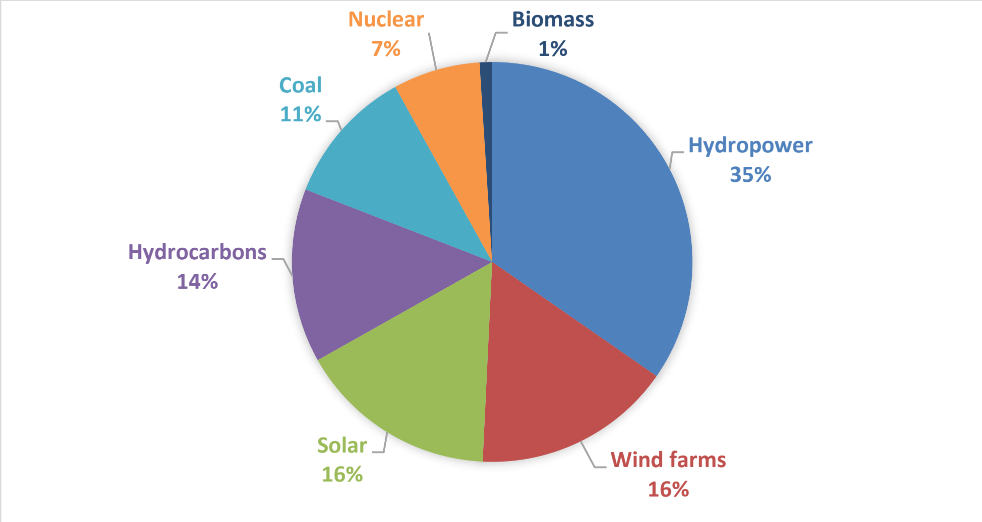

Figure 3. Net installed electricity capacity in Romania, by sources, 2025
(Source: Transelectrica, 2026)

As natural gas has been considered a transitional energy in the short and medium term, necessary to stabilize the electricity grids, two natural gas energy projects have been implemented in Romania and are in an advanced phase of implementation (2026-2027). These are the Mintia power plant (Hunedoara County), with a capacity of 1,700 MW, the largest project of this type in Europe, and the Iernut power plant (Mureș County), with a capacity of 430 MW.

Amid the strong growth in investments in recent years in renewable sources, characterized by variable/intermittent production, pressures have been created on the energy sector's ability to balance consumption and production taking into account the variability of both.

Since 2019, Romania has become a net importer of electricity. The National Institute of Statistics (INS, 2026) reported that in 2025 Romania recorded a significant advance in both electricity exports and imports compared to 2024. Exports were 14.5 TWh (up by almost 34%), and imports were 18.2 TWh (up by 32%). The problem is that, in recent years, Romania has exported energy at peak production, when the price was low, and imported at peak consumption, when the price was high. During the day, when wind turbines and solar panels produced a lot, there was a surplus of energy. To avoid overloading the network, producers had to sell this surplus on the market, often at very low or even negative prices. Because constant energy production (hydropower, nuclear, coal, gas) decreased, Romania could not meet domestic demand with its own resources alone.

According to an analysis by the Smart Energy Association (AEI), cited by Agerpres (2026), Romania exported electricity in April 2026 at average prices of around 50 euros/MWh and imported energy during evening peak hours at prices that rose to 250 euros/MWh. In April 2026, Romania imported electricity from Bulgaria worth around 33.4 million euros, while exports to this country amounted to only around 5 million euros. Although the quantity imported was only around twice as much as that exported, the financial value of imports was almost seven times higher. This situation occurs because there is not enough storage capacity to store cheap energy produced by renewable sources, there is no mechanism to shift consumption off-peak, and there is not enough flexibility in production. Aggregated data for 2025 show that 26% of annual imports are concentrated in the 18–21 interval, i.e. right at the price peak (Table 2). In contrast, exports are concentrated in the intervals with lower demand and lower prices, especially 12–15 and during the night (Profit, 2026).

Table 2. Share of average electricity imports/exports in Romania in 2025
(aggregated by 3-hour intervals)

Time slot	Percentage of average annual imports (%)	Average import price (RON/MWh)	Percentage of average annual exports (%)	Average export price (RON/MWh)
00-03	5	620	14	530
03-06	5	623	10	510
06-09	14	723	7	495
09-12	12	720	13	512
12-15	9	713	24	550
15-18	14	823	16	568
18-21	26	893	7	610
21-24	14	750	10	562

Source: Electricity and Natural Gas Market Operator (cited by Profit, 2026)

Therefore, balancing the power system has become an essential issue, and the use of the technical and economic potential of renewable energy sources depends largely on the development of storage capacities.

The first public utility BESS in Romania was inaugurated in October 2018. It was developed by EDP Renewables within the Cobadin 1 wind farm in Constanța County, with a capacity of 1.26 MW (1.36 MWh). The equipment (batteries and inverters) were supplied by Siemens and mounted in special dedicated containers (EnergoBit, 2018).

In 2024-2025, the Monsson group developed the largest hybrid project (photovoltaic-wind-battery) at that time, using domestic batteries produced by Prime Batteries Technologies. In August 2025, the system became the first in Romania and Europe to be officially certified by DNV Renewables Certification GmbH for safety. In 2025, the storage capacity put into operation in the first two phases was 72 MWh. This capacity is projected to reach a total of 216 MWh after the third phase. Active in the renewable energy sector in Romania for over 20 years, Monsson has become a major supplier of renewable electricity, with a portfolio of over 5 GW in wind and solar projects (Monsson, 2025). In July 2026, the Nova Power & Gas project in Florești (Cluj County), launched in December 2025, was the largest operational BESS in Romania, with an installed power of 200 MW and a storage capacity of 400 MWh.

Hidroelectrica is the largest producer of electricity from renewable sources in Romania and one of the most important players in the energy sector of South-Eastern Europe. With a portfolio of over 6.3 GW of installed capacity in hydropower plants and the Crucea wind farm (108 MW), the company contributes to national energy security and to achieving the decarbonization objectives set by EU policies. The Crucea Nord BESS project is the first facility of this type developed by Hidroelectrica, with a storage capacity of 72 MWh. On 22 April 2026, Hidroelectrica signed a contract for non-reimbursable financing, obtained through the Modernization Fund, for the implementation of a BESS at the Porțile de Fier II HPP. The project provides for the installation of a storage capacity of 256 MWh, being the largest BESS developed by the company to date (Hidroelectrica, 2026).

Other companies, such as: Simtel & Energy Capital Group, Eurowind Energy & Allview, Premier Energy, R. Power Renewables, PPC Renewables Romania, Electrica or eBattery.Energy have developed BESS in Romania (Table 3).

Prime Batteries Technology is the main local industrial player. Founded in 2016, the company has its headquarters and production facilities in Romania (in Căldăraru, Ilfov County) and has become a strategic player at European level in the renewable energy sector. This company produces cells and systems based on lithium iron phosphate (LFP) technology, securing the supply chain for local projects. The projects of Monsson (from Mireasa) and Eurowind Energy & Allview (from Teiuș) have used batteries produced by Prime Batteries Technology.

If at the beginning of 2024, the energy storage capacity in batteries in Romania was only 16 MWh, at the beginning of August 2026 it reached a capacity of 1975 MWh, i.e. 989 MW of installed power. In the first part of 2026 alone, from late April to early August, almost 900 MWh were installed (Transelectrica, cited by Economica, 2026a). In addition, the over 300,000 prosumers had an installed power in batteries of over 800 MW (APCE, 2026).

As a result of the prospects for increasing electricity consumption (in industry, transport, services, agriculture or housing), but also as a result of the commitments to meet the targets for reducing greenhouse gas emissions by increasing the share of renewable energy sources and energy efficiency in all sectors, within the framework of the Romanian Energy Strategy 2025-2035, with a view to 2050, one of the specific objectives for achieving these targets is the development of energy storage capacities (Ministry of Energy, 2024).

Table 3. BESS projects operational and under development in Romania

Company	Location	Installed power (MW)	Storage capacity (MWh)	Current status
Monsoon (Phase 1)	Gălbiori (Constanța County)	-	24	Operational (April 2024)
Nova Power & Gas (E-INFRA)	Florești (Cluj County)	200	400	Operational (December 2025)
Simtel & Energy Capital Group	Iaz (Caraș Severin County)	100	206	Operational (May 2026)
Aukera Energy (Faza 1)	Gura Ialomiței (Ialomița County)	150	300	Operational (June 2026)
Hidroelectrica	Crucea Nord (Constanța County)	36	72	Operational
Eurowind Energy & Allview	Teiuș (Alba County)	-	120	Project completed in June 2026
LJG Green Source Energy Gamma	Izvoarele (Giurgiu County)	42.5	160	Project completed in July 2026
Aukera Energy (Phase 2)	Gura Ialomiței	100	200	In development
Premier Energy	Iași County	200	400	In development
R.Power Renewables	Scornicești (Olt County)	127	254	In development
Hidroelectrica	Porțile de Fier II (Mehedinți County)	64	256	In development
PPC Renewables România	Nicolae Bălcescu (Constanța County)	60	120	In development
Electrica	Fântânele (Mureș County)	35	70	In development
eBattery.Energy	Zalău, Satu Mare, Seini	30 (cumulative)	60 (cumulative)	3 projects in development

Source: Monsson, 2024; Aukera Energy, 2024; Eurowind Energy, 2026; LSG Group, 2026; Economica 2026a; R. Power Renewables, 2025; PPC, 2026; InvesTenergy, 2026; Hidroelectrica, 2026; Electrica, 2025; eBattery.Energy, 2025

To mitigate the effects of the massive integration of renewable sources in the period 2025-2030, Transelectrica assesses a need for 2000-4000 MW of installed power in storage facilities. The objective is a total installed power of electricity storage of at least 2000 MW by 2030, achieved both through the installation of BESS and the development of pumped storage hydropower plants (Ministry of Energy, 2024).

The development of the BESS sector in Romania has been directly supported by various funding programs, such as the National Recovery and Resilience Plan (PNRR), the Modernization Fund or the Environmental Fund Administration (AFM). The European Commission has approved state aid schemes dedicated to supporting storage facilities. Through the PNRR, Romania has undertaken to install a capacity of 480 MWh in batteries by June 30, 2026 (Ministry of Energy, 2024). The projects Aukera Energy from Gura Ialomiței, Simtel & Energy Capital Group from Iaz, Eurowind Energy from Teiuș or Electrica from Fântânele have received funding through the PNRR.

The Modernization Fund (operational in Romania since May 2022) finances the addition of BESS next to existing photovoltaic and wind farms, such as the Zephyr 1 project developed by PPC Renewables Romania in Constanța County or the Hidroelectrica project at Porțile de Fier II. The battery energy storage program, with an allocation of RON 400 million, represents one of the main strategic directions introduced in the AFM budget for 2026 and responds to the current needs of the national energy system (AFM, 2026).

The BESS project in Scornicești, developed by R.Power Renewables in Olt County, has benefited from EUR 44 million in financing from the EBRD to support the energy transition. It is one of the largest stand-alone battery projects (R.Power Renewables, 2025). Similarly, eBattery.Energy's BESS projects in Zalău, Seini and Satu Mare represent a private investment of EUR 3.5 million each, for a cumulative installed capacity of 30 MW/60 MWh (eBattery.Energy, 2025).

4. DISCUSSION

Battery energy storage systems are considered vital for the green transition, but they present certain major risks and challenges, such as: environmental issues, battery wear and performance degradation, vulnerability to extreme temperatures, fire risk, or the cost of BESS.

4.1. Environmental issues

The battery industry can generate considerable amounts of pollutants (greenhouse gas emissions and toxic gases) and hazardous waste during various processes such as mining, manufacturing, use, transportation, collection, storage, treatment, disposal and recycling (Dehghani-Sanij et al., 2019). The production of the base materials (lithium, cobalt, nickel) involves intensive mining that consumes large volumes of water and energy, pollutes local water resources and degrades the soil in the mining areas. Battery manufacturing is an energy-intensive process. For every kWh of storage, between 60 and 90 kg of CO2 are emitted, meaning that large systems have a significant climate impact before they are even put into operation. If not disposed of properly, heavy metals and electrolytes from used batteries can contaminate soil and groundwater. Although there is progress in the adoption of battery sustainability rules and recycling technologies, the processes for extracting reusable materials are complex and require energy themselves. The land area occupied can also be significant. For example, the BESS project of R.Power Renewables in Scornicești (Olt County) will be developed on a 75,000 m² land initially used for agriculture (R.Power Renewables, 2025).

4.2. Battery wear and degradation

Currently, the standard designed battery life is around 20 years, as LFP technology has enabled longer life. Performance guarantees can be expressed in years or cycles: in years, guarantees are often 20 or even 25 years, and in cycles, they are typically 10,000-12,000 cycles or more (which, at one cycle per day, means more than 25 years). By the end of the designed life, the electrical energy delivered by the battery will be lower due to degradation. Manufacturers typically guarantee an annual degradation of ≤2%, which means that after 20 years, the capacity remains at around 65% of the initial usable energy. More intense cycles lead to faster degradation and a shorter life (Ember, 2025).

Reliable and efficient operation of lithium-ion batteries is essential for their overall performance in energy storage and conversion. During operation, issues such as battery aging and performance degradation occur. Battery aging can lead to reduced storage capacity, reduced charge and discharge capabilities, increased internal resistance, and increased safety risks. The main factors contributing to battery degradation are lithium stock loss, active material loss, and conductive loss. External factors that influence battery aging during operation include temperature, charge/discharge current, and overcharge or overdischarge. Electrical stresses, such as current fluctuations and overcharge/overdischarge, are major factors contributing to capacity loss and performance degradation of energy storage batteries (Xie et al., 2025).

Investigation of the aging behavior and thermal stability of lithium batteries under mild overcharge conditions indicated that capacity degradation occurs in two distinct phases: a slow phase, caused by the loss of active lithium ions from the anode, and a fast phase, due to the degradation of active materials in the cathode. Higher overcharge voltages lead to more severe damage to the cathode materials. In addition, lithium-ion batteries are assembled in battery packs that include multiple cells. Overcharge can occur due to battery pack inconsistency even with sophisticated battery management systems. Overcharge accelerates battery aging and results in failures and thermal fluctuations, explosion in case of severe problems (Liu et al., 2020).

4.3. Vulnerability to extreme temperatures

Battery energy storage systems are extremely sensitive to extreme temperatures. Operating outside of the optimal temperature range (15°C-35°C) reduces efficiency, accelerates aging, and can lead to catastrophic failure. When batteries operate at high temperatures, several negative effects occur simultaneously. High temperatures increase internal resistance, reducing the battery's ability to deliver energy efficiently. Chemical reactions inside the cells accelerate beyond optimal levels, causing faster degradation of active materials and reducing overall lifespan. The most important aspect is excessive heat that can trigger thermal runaway, in which the battery generates more heat than it can dissipate, leading to a self-sustaining reaction. Low temperatures present different but equally problematic challenges. Low temperatures slow down chemical reactions, reducing available capacity and power output. Charging cold batteries can cause lithium plating, permanently damaging the cells and creating safety hazards. To monitor temperature, BESSs include a battery management system, which continuously monitors the condition of individual cells and ensures safe and optimal operation by preventing overcharging, deep discharge, and thermal fluctuations that could lead to dangerous conditions. These systems often include sophisticated cooling and ventilation systems to remove heat and maintain stable temperatures (Solarif Group, 2026).

4.4. Fire risk

BESS are safe in normal use, but pose serious risks if damaged, overcharged, improperly installed or if protection systems fail. Batteries naturally produce heat when charged or discharged. This happens because electrical energy is converted into chemical energy (when charging) and back into electrical energy (when discharging). Some of this energy is converted into heat instead of being fully used for storage or production (EticaAG, 2025).

The greatest danger is thermal runaway, a chain reaction in which cells rapidly overheat, leading to fires and even explosions. Lithium-ion batteries contain flammable electrolytes, which can create unique hazards when the battery cell is compromised. The initiating event is often a short circuit, which can be the result of overcharging, overheating or mechanical abuse. During the process, large amounts of flammable and potentially toxic gas are generated. The gas released contains mostly hydrogen, which is highly flammable under a wide range of conditions. This can create an explosive atmosphere in the battery chamber or storage container. As a result, a number of recent incidents have had significant consequences, highlighting the difficulties in how to safely manage the hazard (Conzen et al., 2023). Lithium battery fires are extremely difficult to extinguish, with the risk of reigniting hours or even days after the incident.

Poor thermal management has been a significant factor in multiple large-scale fire incidents for BESS worldwide. Investigations show that poor cooling strategies, insufficient ventilation, and external environmental factors contributed to these catastrophic failures. A notable example is the 2019 fire at the McMicken battery storage facility in Arizona, which resulted from a runaway thermal event. This fire caused significant damage and resulted in injuries to emergency responders due to an unexpected explosion. Similarly, in 2022, a fire at a BESS facility in California resulted in massive power outages to limit the risk. These cases highlight the critical need for effective thermal management solutions to prevent overheating and fire spread (EticaAG, 2025). Also, since 2017, at least 27 fires have been reported in South Korea. Twenty-three of the BESS fires were recorded in 2018 (Conzen et al., 2023).

4.5. BESS Cost

According to Ember, in October 2025, in global markets outside of China and the United States, the total capital expenditure for building a large-scale long-duration (4 hours or more) BESS project was approximately $125/kWh, of which approximately $75/kWh was for the core equipment shipped from China and approximately $50/kWh for battery installation and connection. The core equipment, mainly the BESS housings, power conversion system (PCS), and energy management system (EMS), cost around $75/kWh when shipped from China to countries with low import duties. This levelized cost of storage (LCOS) comes from cheaper batteries and lower financing costs (rapid factory expansion, fierce competition, oversupply). The cost of basic BESS equipment decreased by 40% in 2024 compared to 2023, reaching a record low of 165 USD/kWh. Over the past 10 years, installation costs have decreased by an average of 20% per year, while the implementation of new projects has increased by about 80% per year (Ember, 2025; Figure 4).

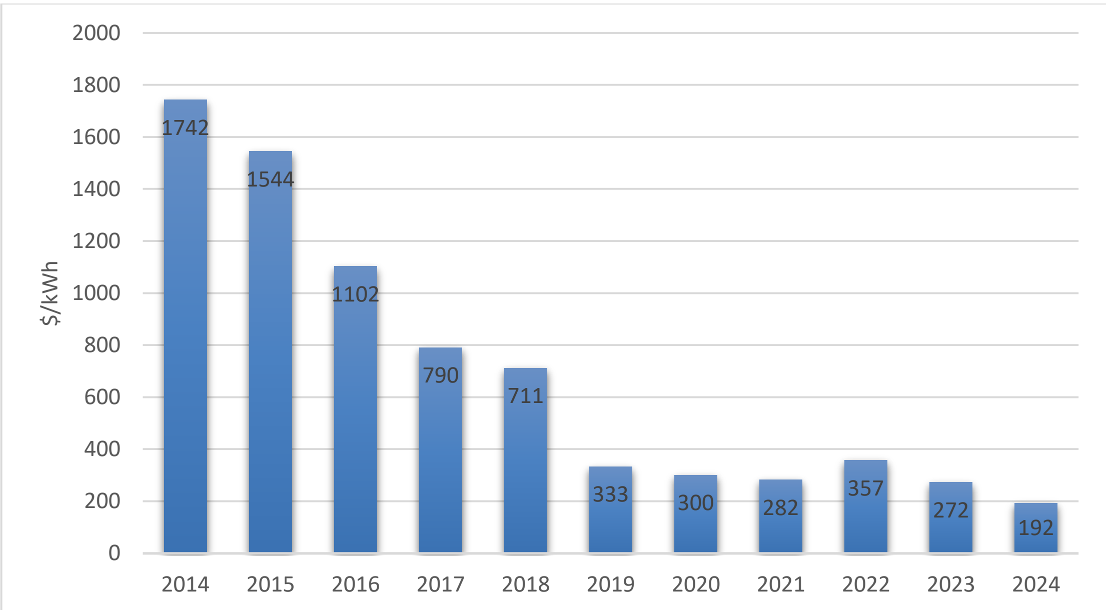

Figure 4. Total installed project cost (Costs of a fully installed and commissioned battery storage project)
Source: IRENA, cited by Ember, 2025

4. CONCLUSIONS

It is a widely accepted fact that greenhouse gases from the combustion of fossil fuels, especially in the energy industry, are responsible for climate change. Also, socio-economic development has led to a continuous increase in energy consumption. In these conditions, renewable energy has been greatly encouraged, and many coal-fired power plants have been closed.

A significant problem of renewable energy, such as solar and wind, is its intermittent nature, and fluctuations in electricity demand throughout the day cause major imbalances in energy systems and high electricity prices. To solve these problems, energy storage systems, including BESS, have been considered an effective solution. Romania is one of the countries that has developed a lot of photovoltaic and wind energy and closed coal-fired power plants. Under these conditions, imbalances in the energy system and large fluctuations in electricity prices have emerged.

Globally, BESS capacity has grown significantly in recent years. Considerable progress has been made, including in terms of installation costs, but certain risks and challenges persist, such as environmental issues, battery wear and degradation, and fire risk.

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