Seminar Paper

Relevance and Costs of Long- and Short-Term Energy Storage Systems: A Case Study of the Czech Republic and Austria in the EU Context

written by

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List of abbreviations

BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CAES	Compressed Air Energy Storage
CfD	Contracts for Difference
EAG	Erneuerbaren-Ausbau-Gesetz (Renewable Expansion Act, Austria)
EASE	European Association for Storage of Energy
EIB	European Investment Bank
EU	European Union
FCR	Frequency Containment Reserve
GWh	Gigawatt hour
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LDES	Long Duration Energy Storage
LFP	Lithium Iron Phosphate
LTES	Long-Term Energy Storage
MW	Megawatt
NECP	National Energy and Climate Plan
NPUC	National Public Utility Council
OPEX	Operational Expenditure

PHS	Pumped Hydro Storage
PTES	Pumped Thermal Energy Storage
RAG	Rohöl-Aufsuchungs Aktiengesellschaft (Austria)
RRF	Recovery and Resilience Facility
SNG	Synthetic Natural Gas
VRES	Variable Renewable Energy Sources

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1. Introduction

The European Union has set ambitious goals to combat climate change, committing to a transition towards a carbon-neutral economy by 2050 (Hiris et al., 2024). This target necessitates a significant transformation of the energy system, with a central pillar being the large-scale deployment of renewable energy sources like solar and wind power (European Investment Bank, 2024). These variable renewable energy sources, while crucial for decarbonization, present a unique challenge due to their intermittent nature, as their output depends on weather conditions rather than consistent dispatchability. To effectively integrate these VRES into the energy mix and ensure a stable and reliable power supply, long-term energy storage (LTES) systems, capable of storing energy for periods ranging from weeks to months, are of paramount importance (*Unlimited Energy Storage in Europe*, 2025). Furthermore, the current geopolitical landscape, particularly the strategic imperative to reduce reliance on Russian gas and enhance overall energy security, further underscores the urgency for developing robust LTES solutions (*Long Duration Energy Storage*, 2024).This report aims to provide a comprehensive analysis of the relevance and costs of long-term energy storage systems within the European Union, using the Czech Republic and Austria as specific case studies to illuminate the challenges, opportunities, and policy considerations in this critical area of the energy transition.

2. The Role of Energy Storage in the Energy Transition

The increasing integration of variable renewable energy sources into the European Union's energy system necessitates robust solutions to address their inherent intermittency. Long-term energy storage systems play a critical role in capturing excess renewable energy generated during periods of high production, such as sunny summers for solar power or windy seasons, and storing it for use during periods of low generation, like winter months with less sunlight or calm periods with minimal wind (European Investment Bank, 2024). This capability ensures a more consistent and reliable energy supply, mitigating the fluctuations associated with weather-dependent renewables (European Investment Bank, 2024). The rising frequency of extreme weather events further amplifies the importance of LTES, as these systems can provide a stable energy source during prolonged disruptions to both renewable generation and traditional power infrastructure (NPUC, 2024). The ability of LTES to decouple energy generation and consumption over extended periods signifies a fundamental shift towards a more flexible and resilient energy system, essential for a future dominated by renewable sources (European Investment Bank, 2024).

Beyond managing intermittency, long-term energy storage is crucial for enhancing grid stability and resilience. These systems can offer essential grid services, including frequency regulation, voltage support, and inertia, which are vital for maintaining the operational integrity of power grids with a growing share of VRES (European Investment Bank, 2024). Furthermore, LTES can alleviate grid congestion and reduce the need to curtail renewable energy generation, thereby optimizing the utilization of existing grid infrastructure and minimizing energy waste (EASE, 2022). The role of LTES in enabling grid decentralization and supporting the integration of distributed energy resources, such as rooftop solar and community-scale wind projects, further underscores its importance in modernizing the power system (EASE, 2022). By acting as a buffer, LTES absorbs excess energy and releases it when demand is high or supply is limited, playing a pivotal role in preventing grid failures and bolstering overall system resilience, particularly as the grid evolves with more diverse and geographically dispersed generation sources (European Investment Bank, 2024).

Ensuring energy security and reducing the European Union's reliance on fossil fuels are also key drivers for the deployment of long-term energy storage. By facilitating the greater use of domestically generated renewable energy, LTES can significantly decrease the EU's dependence on imported fossil fuels, thereby enhancing energy security and resilience to geopolitical risks and volatile global markets (European Investment Bank, 2024). Moreover, LTES offers the potential to replace traditional gas peaker plants, which are often utilized to meet peak electricity demand but rely on fossil fuels, with cleaner and more sustainable solutions (NPUC, 2024). The ability of LTES to support the electrification of other energy-consuming sectors, such as transportation and heating, with clean, renewable energy further contributes to energy security and decarbonization efforts (European Investment Bank, 2024). Investing in LTES represents a strategic move towards greater energy independence and a more secure energy future for the EU, maximizing the utilization of indigenous renewable resources and mitigating vulnerabilities associated with fossil fuel dependence.

Ultimately, long-term energy storage is a central enabler for achieving the European Union's ambitious decarbonization goals. By providing the necessary flexibility and reliability, LTES allows for a significantly higher share of renewable energy in the overall energy mix, paving the way for the eventual phase-out of carbon-emitting power plants (European Investment Bank, 2024). Furthermore, LTES helps avoid the curtailment of valuable renewable energy generation, ensuring that clean energy resources are fully utilized and not wasted (EASE, 2022). The potential of LTES to contribute to the decarbonization of industrial processes and the heating sector through enhanced sector coupling further highlights its transformative role in building a sustainable energy future (EASE, 2022). By addressing the challenge of renewable energy intermittency, LTES acts as a linchpin in the transition to a clean energy system, ensuring that renewable sources can reliably meet energy demands across various timescales and sectors.

3. Overview of Energy Storage Technologies

A diverse range of technologies are being developed and deployed for long-term energy storage, each with unique technical specifications and typical applications.

3.1. Mechanical Storage Technologies

Pumped Hydro Storage (PHS) stands as the most mature and widely implemented large-scale energy storage technology (Zablocki, 2019). PHS systems typically have a large storage capacity, ranging from 10 MW to 3 GW, and can provide energy for a minimum of several hours, often up to 10 hours or more. These systems boast a high round-trip efficiency of 70-85% (Zablocki, 2019) and are primarily used for large-scale bulk energy storage, managing high penetrations of renewable energy, and providing essential grid reliability services (Zablocki, 2019). While PHS is a proven technology with a long lifespan, its deployment is often geographically constrained by the need for suitable topography with elevation differences and water reservoirs (Zablocki, 2019).

Compressed Air Energy Storage (CAES) represents another established mechanical storage technology suitable for large-scale applications, with capacities ranging from 10 to 300 MW and discharge durations of several hours up to around 10 hours (Zablocki, 2019). The round-trip efficiency of CAES systems can vary, with adiabatic CAES (A-CAES), which stores the heat of compression, achieving efficiencies greater than 70%, while other CAES variants typically range from 40-70% (Zablocki, 2019). CAES is primarily used for large-scale energy storage, providing peaking power, and enhancing grid stability (Zablocki, 2019). A key requirement for CAES is the availability of suitable geological formations, such as underground caverns, for air storage (Zablocki, 2019).

Gravity-based storage is an emerging mechanical technology that harnesses gravitational potential energy by lifting heavy weights and releasing them to generate electricity (NPUC, 2024). These systems can have capacities ranging from 20 to 1000 MW and discharge durations up to 15 hours, with a high round-trip efficiency of 70-90% (NPUC, 2024). Gravity-based storage is being explored for grid stabilization, renewable energy integration, and offers potentially flexible siting options compared to PHS (NPUC, 2024). While still in the pilot stage for very long durations, this technology utilizes established mechanical principles and offers promising scalability (NPUC, 2024).

3.2. Thermal Storage Technologies

Sensible heat storage involves storing thermal energy by increasing the temperature of a medium like water, molten salts, or solid materials (Xu et al., 2014). These systems can achieve very long durations, up to 200 hours, with capacities ranging from 10 to 500 MW and round-trip efficiencies of 55-90% (Xu et al., 2014). Sensible heat storage is particularly suitable for seasonal storage and meeting heating and cooling demands using renewable energy sources, especially in district heating applications (Xu et al., 2014).

Latent heat storage utilizes the heat absorbed or released during the phase change of a material to store thermal energy (Hiris et al., 2024). These systems can store energy for hours to days and offer a higher energy storage density compared to sensible heat storage, although their round-trip efficiency can be lower, ranging from 20-50% (Hiris et al., 2024). Latent heat storage is suitable for shorter-term storage applications where temperature stability during charging and discharging is important (Hiris et al., 2024).

Thermochemical storage stores energy within the chemical bonds of materials through reversible chemical reactions (Bao & Ma, 2022). This technology has the potential for very long duration storage, potentially weeks to months, and offers high energy density. While promising for seasonal storage, thermochemical storage faces challenges related to efficiency and safety (Bao & Ma, 2022).

Pumped Thermal Energy Storage (PTES) is a technology designed for medium to longer duration energy storage, potentially reaching GWh capacities (Sharma & Mortazavi, 2023). PTES offers low cost, scalability, and flexibility in deployment, with a long asset life exceeding 50 years and no chemical or fire risks (Sharma & Mortazavi, 2023). These systems can provide grid-scale energy storage, meet high power needs, and offer grid inertia and other ancillary services by utilizing advanced supercritical CO2 technology and proven components (Sharma & Mortazavi, 2023).

3.3. Chemical Storage Technologies

Power-to-Gas-to-Power, primarily involving hydrogen storage, offers the potential for very long duration energy storage, ranging from 500 to 1000 hours, with a round-trip efficiency of 40-70% (NPUC, 2024). This technology involves using electricity to produce hydrogen through electrolysis, storing the hydrogen, and then using it in fuel cells or combustion turbines to generate electricity when needed. Hydrogen storage is particularly suited for seasonal storage and can act as a transportable energy carrier (Shabanpour-Haghighi & Karimaghaei, 2022). While it allows for a very long energy storage, it faces challenges related to safety, efficiency, and the development of necessary infrastructure (Shabanpour-Haghighi & Karimaghaei, 2022). Power-to-gas technologies, such as hydrogen and synthetic natural gas (SNG), are considered promising solutions for long-term storage, addressing weekly and monthly variations in renewable energy supply (Shabanpour-Haghighi & Karimaghaei, 2022).

Approximately 6.5% of the annual electricity demand would need to be allocated for long-term storage using these methods to support a fully renewable Europe (IRENA, 2020). The Czech Republic is exploring the potential of hydrogen storage in underground facilities, indicating a strategic interest in this technology capable of storing large amounts of energy for extended periods. Austria is also actively researching underground hydrogen storage as a means of storing surplus renewable energy from the summer for use during the winter months, particularly for heating and electricity (RAG Austria AG, 2021). RAG Austria AG is exploring seasonal energy storage in the form of renewable gases, including their "Underground Sun Storage" project which involves storing hydrogen, produced from renewable solar energy, in a depleted natural gas reservoir with a capacity of 4.2 GWh.

3.4. Electrochemical Storage Technologies

Flow batteries represent a promising electrochemical technology for long-term energy storage, offering durations ranging from 25 to 100 hours, with a round-trip efficiency of 50-80% and a long cycle life (Alotto et al., 2014). The energy capacity of flow batteries can be easily scaled by increasing the volume of the electrolyte stored in external tanks (Alotto et al., 2014). They are suitable for load following, peaking capacity, and other longer duration services, and are generally considered safer than lithium-ion batteries and less reliant on rare materials. However, flow batteries typically have higher upfront costs compared to lithium-ion and lower energy and power density (Alotto et al., 2014).

Advanced battery technologies, such as metal anode batteries and hybrid flow batteries, are also being explored for long-duration energy storage applications (NPUC, 2024). Metal anode batteries can achieve durations of 50-200 hours with a round-trip efficiency of 40-70%, while hybrid flow batteries offer durations of 8-50 hours and an efficiency of 55-75% (NPUC, 2024). These technologies aim to provide long-duration flexibility with potentially lower costs and high scalability by experimenting with different chemistries and materials (NPUC, 2024).

Table 1: Technical Specifications of Key Long-Term Energy Storage Technologies (NPUC, 2024; Zablocki, 2019)

Technology	Max. Power Output (MW)	Nominal Duration (Hours)	Average Round-Trip Efficiency (%)	Typical Applications	Key Insights
Pumped Hydro Storage (PHS)	10 - 3000	min - 10+	70 - 85	Large-scale bulk storage, renewable integration, grid reliability	Mature, large capacity, geographically constrained, high upfront cost
Compressed Air Energy Storage (CAES)	10 - 1000	hours - 10+	40 - 70 (A-CAES >70)	Large-scale storage, peaking power, grid stability	Requires geological formations, A-CAES more efficient
Gravity-Based Storage	20 - 1000	0 - 15	70 - 90	Grid stabilization, renewable integration, flexible siting potential	Emerging, flexible siting, high RTE
Sensible Heat Storage	10 - 500	200	55 - 90	Seasonal storage, heating/cooling with renewables, district heating	Uses readily available materials, high temperature storage
Latent Heat Storage	-	hours - days	20 - 50	Shorter-term storage, temperature stability	Higher energy density than sensible heat, efficiency can be lower
Thermochemical Storage	-	weeks - months	40 - 70	Seasonal storage, high	Indefinite storage potential,

				energy density potential	efficiency and safety challenges
Pumped Thermal Energy Storage (PTES)	-	medium - longer (GWh)	70 - 75	Grid-scale, high power needs, grid inertia, ancillary services	Low cost, scalable, flexible, long asset life, sustainable
Power-to-Gas-to-Power (Hydrogen)	10 - 100	500 - 1000	40 - 70	Seasonal storage, transportable energy carrier	Indefinite storage, safety and efficiency challenges, infrastructure needed
Flow Batteries	10 - 100	25 - 100	50 - 80	Load following, peaking capacity, longer duration services, safer than Li-ion	Scalable by electrolyte volume, long cycle life, higher upfront cost than Li-ion
Advanced Batteries	10 - >100	8 - 200	40 - 75	Long-duration applications	Exploring various chemistries for long duration, potential for high scalability and low cost

Table 2: Cost Comparison of Different Long-Term Energy Storage Technologies (Estimates)(Giovinetto & Eller, 2019)

Technology	**Estimated CAPEX (€/kWh)**	**Estimated OPEX (% of CAPEX)**	**Typical Lifespan (Years)**
Pumped Hydro Storage (PHS)	370 - 440	-	50 - 100
Compressed Air Energy Storage (CAES)	270 - 550	1 - 2	30+
Gravity-Based Storage	170 - 600	-	30+

Sensible Heat Storage	120 - 450	1 - 3	20 - 50
Latent Heat Storage	150 - 500	1 - 3	15 - 30
Power-to-Gas-to-Power (Hydrogen)	180 - 550	2 - 5	20 - 30
Flow Batteries	350 - 600	2 - 4	20 - 30
Advanced Batteries	-	-	10 - 20+
Pumped Thermal Energy Storage (PTES)	15 - 20	-	50+
Liquid CO2 Storage	~180 ($/kWh)	~3.7%	30+

4. Energy Storage in the Czech Republic

4.1. Current Storage Capacity

As of 2023, the Czech Republic's energy storage capacity is still relatively small compared to larger European economies. The dominant form of energy storage is pumped hydroelectric storage, which accounts for over 96% of total national storage power capacity of 1190 MW. (Joint Research Centre, 2025) The three major pumped-storage plants—Dlouhé stráně, Dalešice and Štěchovice II—represent a combined installed capacity of around 1150 MW, with Dlouhé stráně alone providing 650 MW. These systems are essential for grid balancing and providing ancillary services, especially in the context of increasing renewable energy integration. Main parameters of the PHSs in the country are listed in the table below. After 2030 an enhancement of a current Orlík hydroelectric power plant is planned. This should bring another 440 MW of energy storage power capacity. (Czech Ministry of the Environment, 2024) Current energy storage sites and sites under construction in the Czech Republic are shown in Figure 1.

Table 3 Key parameters of Czech PHSs in operation (ČEZ a.s., 2025) (*OM Solutions*, 2018)

	Power (MW)	Energy capacity (GWh)	Commissioning date
Dlouhé Stráně	650	3,7	1996
Dalešice	480	2,3	1978
Štěchovice II	22,5	0,95	1944

Battery energy storage systems (BESS) are still in their infancy, though growing. By the end of 2023, the Czech Republic had installed approximately 40 MW of grid-scale battery capacity (ČEPS a.s., 2023). Most of these systems are lithium-ion-based and are used in pilot projects or by industrial users for peak shaving, backup, and frequency regulation (FCR). The deployment of BESS is expected to rise as prices continue to fall and regulatory frameworks adapt to new market conditions. An example of legislative state support is the amendment known as *Lex OZE III*, approved in spring 2025, which expands the possibilities for the implementation of battery storage systems. This legislative development is expected to significantly boost further investment in the energy storage sector. (Czech Ministry of industry and trade, 2025)

4.2. Government Policies and Incentives

Government support for energy storage is emerging gradually. A key document is the Mid-Term Adequacy Forecast (MAF) 2023 published by ČEPS, the Czech TSO. It highlights the increasing role of flexibility sources, particularly in the context of growing intermittent renewable energy sources like solar and wind. The MAF recognizes storage as a critical tool for maintaining system adequacy and encourages investment into modern technologies, including BESS and thermal storage. It also emphasizes the role of hydrogen in the future energy mix, which creates opportunities for the use of hydrogen storage systems. In the progressive scenario, it estimates an installed fuel cell capacity of 5 MW by 2030. (ČEPS a.s., 2023)

The National Energy and Climate Plan outlines goals to increase the share of renewables to 22% of gross final energy consumption by 2030. This increase will necessitate greater grid flexibility, incentivizing energy storage indirectly. In 2022 and 2023, Czechia introduced calls for support under the Modernisation Fund, especially the RES+ program, which allows co-funding of energy storage projects tied to renewable installations. (Czech Ministry of industry and trade, 2024)

4.3. Economic feasibility and financing of projects

As mentioned above, the economic feasibility of certain types of energy storage in the Czech Republic is limited, and larger projects are associated with relatively high investment costs. The financing of such projects often involves both national and European subsidy initiatives and support schemes.

At present, there is no active subsidy program in the Czech Republic specifically aimed at supporting energy storage systems. However, in the case of constructing a new PHS facility, the government is prepared to act as an investor through state-owned or semi-state enterprises. (Czech Ministry of the Environment, 2024)

At the European level, several forms of financial support are available. The European Investment Bank (EIB) has been instrumental in financing the modernization of Czechia's energy infrastructure. Notably, the EIB extended a €790 million loan to ČEZ, the country's leading energy utility, to expand and modernize the national electricity distribution network. (European Investment Bank, 2022) In March 2025, the European Commission approved a €279 million Czech scheme aimed at fostering investments specifically in electricity storage facilities. This initiative is designed to enhance flexibility in the electricity system and support the integration of renewable energy sources. The scheme is anticipated to facilitate the deployment of approximately 1.5 GWh of energy storage projects across Czechia. (Directorate-General for Communication, 2025)

5. Energy Storage in Austria

Austria possesses significant electricity storage capacity, overwhelmingly dominated by hydropower, benefiting from favorable topographical and hydrological conditions. As of late 2014, Austria's installed generation capacity in storage and pumped storage plants totalled nearly 8,000 MW. This capacity includes approximately 3,600 MW in storage plants without pumping function and 4,400 MW in plants with an additional pumping capacity of around 3,300 MW (Neubarth, 2017). In terms of energy content, Austrian storage and pumped storage plants collectively hold about 3.3 TWh. This represents a substantial volume, equivalent to roughly two to three times Austria's weekly electricity consumption. Specifically focusing on plants with a turbine capacity greater than 50 MW, these represent nearly 90% of Austria's storage and pumped storage park, with a bottleneck capacity of 7,100 MW and an annual working capacity of 9.4 TWh/a. While pumped storage has a smaller energy content relative to pure storage plants (ratio ~1:30 in TWh), its turbine capacity is significant compared to pure storage plants (ratio 1:2 in GW). This difference reflects their primary roles: pure storage plants are suitable for providing high power over longer durations, while most pumped storage plants are designed for shorter-term balancing and daily shifting. There are also ongoing and planned expansion projects for storage and pumped storage plants in Austria until 2035, adding a combined turbine and pump capacity of approximately 3.8 GW each (Baumgartner & Rienessel, 2019).

Alongside the established dominance of pumped hydro, Austria is witnessing the emergence of battery energy storage systems (BESS) as a significant component of its long-term energy storage landscape. NGEN Smart Grid Systems recently completed a 10.3MW/20.6MWh standalone battery storage project in Arnoldstein, which was claimed to be the largest in Austria at the time. This milestone was quickly followed by NGEN's commissioning of an even larger BESS in Fürstenfeld, with a capacity of 12 MW and 24 MWh (Murray, 2023). These projects utilize advanced lithium iron phosphate (LFP) battery technology supplied by Tesla in their Megapack systems. The co-location of the Fürstenfeld project with a wood gas generator and a solar farm indicates a trend towards integrated and hybrid energy solutions (Murray, 2023). While the overall capacity of battery storage is currently smaller than that of pumped hydro, these recent large-scale projects signify a growing recognition of the critical role that shorter-duration, fast-response storage plays in maintaining grid stability and facilitating the integration of intermittent renewable energy sources like solar and wind.

Furthermore, RAG Austria AG operates substantial underground natural gas storage facilities, with a total (possible) capacity of approximately 6.4 billion cubic meters (RAG Austria AG, 2021). This extensive infrastructure represents a significant energy storage asset that holds considerable potential for future repurposing towards hydrogen storage. Given the large volumes and suitable geological characteristics of these existing reservoirs, they offer a potentially cost-effective and timely pathway for the deployment of hydrogen as a long-term, seasonal energy storage medium, which could be crucial for balancing the intermittency of renewable energy over extended periods.

Government Policies and Incentives

Austrian energy policy, framed within EU energy and climate goals, places a strong emphasis on decarbonization and the expansion of renewable energies. The Austrian federal government's Climate and Energy Strategy aims for 100% renewable electricity generation by 2030. In this strategy, hydropower is assigned a key role and its importance for the Austrian electricity sector is expected to increase. This is aligned with the broader goals of Alpine states to modernize their existing hydropower infrastructure to meet the rising flexibility demands caused by the expansion of volatile renewable energy sources like wind and solar power. There is a broad consensus in the energy policy discussion that there is a significant medium- and long-term need for expanding existing storage capacities. European policy frameworks, such as the European Commission's Energy Roadmap 2050 and Energy Infrastructure Priorities for 2020, also view the expansion of electricity storage capacities in Europe as an important element for achieving EU energy and climate targets. These overarching energy policy goals and frameworks are seen as determining the future economic significance and operational requirements for Austrian storage plants.. A key challenge necessitating flexible capacity like pumped storage is the geographical disparity between variable renewable generation (in the East of Austria) and the location of significant hydropower storage capacity (primarily in the Alps - the West of Austria). This spatial separation means that electricity generated from wind and solar in one region must be transported via the grid to demand centers or storage facilities located elsewhere. The sources emphasize that grid expansion is crucial not only to connect the centers of flexible Alpine hydropower with areas producing volatile wind and photovoltaic power, but also to integrate these diverse storage facilities effectively across the Austrian and European system (Baumgartner & Rienessel, 2019).

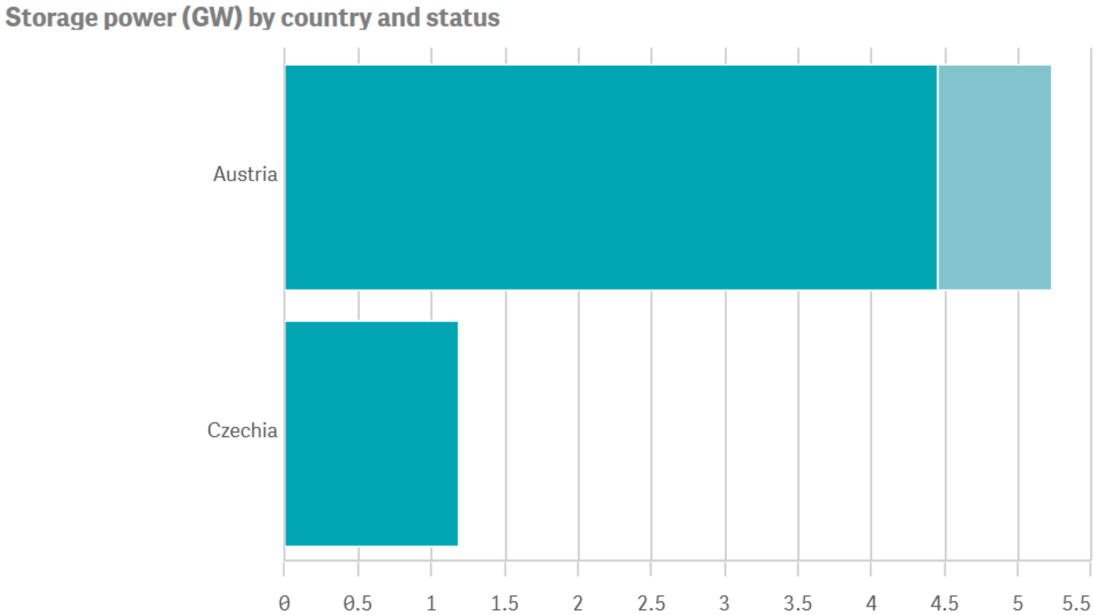
Economic Feasibility and Financing of Projects

The economic feasibility of long-term energy storage projects, particularly pumped storage hydropower in Austria, is closely tied to its ability to provide flexibility and ancillary services to the electricity grid and participate in various market segments.

Hydropower storage offers key technical advantages, including high efficiency (pumped storage 75-82% round-trip efficiency) and very long calendar and cycle lifetimes (>80 years for pumped storage), making it suitable for frequent use. This contrasts favorably with technologies like Power-to-Gas (PtG), which is considered a potential long-term/seasonal storage solution but currently has much lower round-trip efficiencies. While battery storage is competitive for short-duration applications and fast response times, pumped storage is generally more cost-effective for longer discharge durations and higher annual cycling.

Pumped storage plants derive revenue from various market segments, including the Day Ahead market (for daily energy shifting), the Intraday market (for balancing short-term fluctuations), and the reserve markets (providing frequency regulation and system stability) (Neubarth, 2017). The increasing volatility introduced by wind and solar power creates greater need for such flexibility, potentially increasing revenue opportunities for flexible assets like pumped storage. The merit-order effect, where high renewable generation pushes down wholesale electricity prices, creates favorable conditions for pumped storage plants to purchase cheap electricity for pumping. Conversely, they discharge during periods of high demand or low renewable output when prices are higher.

The economic viability of future projects is influenced by market design, grid infrastructure (connecting generation and demand centers), and the specific requirements derived from future energy scenarios (Neubarth, 2017). While historical analysis of some storage plant operations shows patterns influenced by regulations, future operational requirements will be shaped by the evolving energy system and market conditions (Baumgartner & Rienessel, 2019). Overall, despite significant upfront investment, the technical characteristics and market roles of pumped storage underscore its continued relevance and potential economic feasibility in the context of Austria's energy transition.



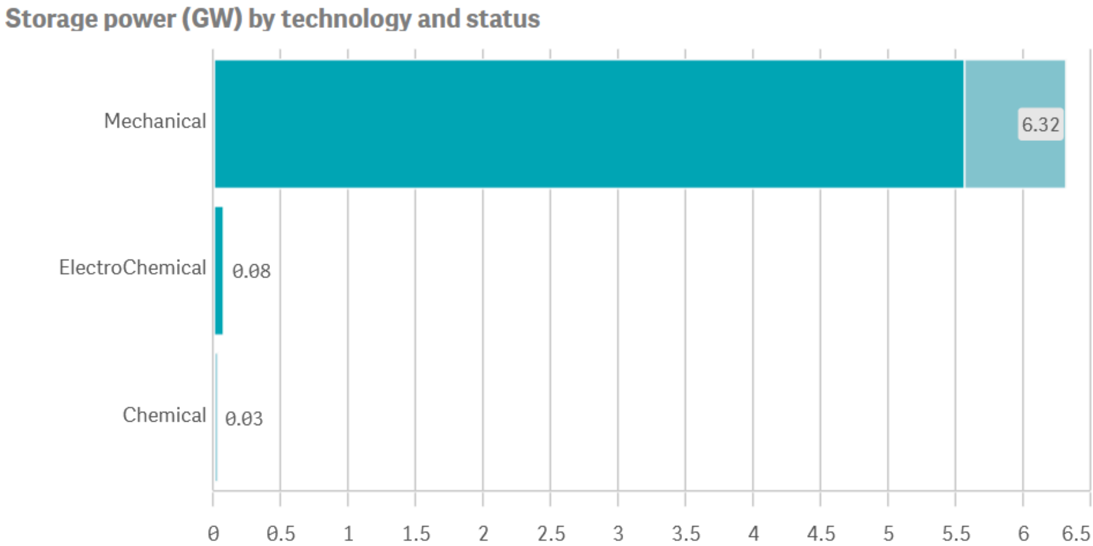


Figure 1 Energy storage power by country and technology (Joint Research Centre, 2025)

6. Trends and future economic needs in for AT/CZ and in the EU

6.1 Storage Targets

The European Union recognizes that achieving climate neutrality by 2050 and a renewable energy share of at least 42.5% by 2030 requires a dramatic expansion of energy storage systems. According to the European Commission's 2023 *Recommendation on Energy Storage* and EASE, the EU will need to increase storage capacity fourteen-fold compared to 2020 levels to maintain grid stability and flexibility (European Commission, 2023; EASE, 2022).
Indicative figures suggest that about 200 GW of storage power capacity, corresponding to roughly 600 GWh of energy capacity, should be deployed across the EU by 2030 to enable large-scale renewable energy integration (EASE, 2022).
Czechia has set a specific target to deploy new energy storage. The Modernisation Fund aims to deploy about 1.5 GWh of battery storage by 2030 (European Commission, 2025). ČEPS's MAF 2023 also estimates the need for hundreds of MW of fast-acting storage, including batteries and hydrogen, within the next decade (ČEPS, 2023).
Austria has set the Target within the "Mission 2030" to achieve a 100 percent electricity supply from renewable energies by 2030, to reduce greenhouse gas emissions by 36 per cent compared to 2005 and to increase the share of renewable energies in gross energy consumption to 45-50 per cent (*Neue Ausbau-Ziele für Österreich bis 2030*, 2024).

6.2 Financial and Regulatory Support

Financial and regulatory frameworks are increasingly supporting energy storage deployment across Europe. At the EU level, initiatives such as the

Modernisation Fund, the Recovery and Resilience Facility (RRF), and financing from the European Investment Bank are providing critical investment resources. For example, Czechia and Austria are leveraging EU-backed programs to support grid modernization and new storage projects. (EIB, 2022)

Recent EU recommendations have also improved regulatory conditions for storage, promoting streamlined permitting, fair grid tariffs, and market access for storage operators. National governments are adapting accordingly: Austria's Renewable Expansion Act (EAG) and Czechia's updated market rules now enable batteries and pumped hydro facilities to participate more fully in energy and balancing markets. (BMK, 2022) (Czech Ministry of trades, 2025) These reforms strengthen the business case for storage and are vital for achieving renewable energy targets.

6.3 Market Trends and Technological Developments

Energy storage technologies are rapidly evolving to meet the flexibility needs of a renewable-based energy system. Battery energy storage systems (BESS) are at the forefront of this growth, driven by declining lithium-ion costs—down nearly 80% over the past decade (IEA, 2023). These systems are increasingly deployed for short-duration applications like frequency regulation and peak shaving. In Austria, large-scale BESS projects have recently been completed, including the 12 MW / 24 MWh Fürstenfeld facility, co-located with renewable sources (Murray, 2023). The country is now planning up to 2.5 GWh of BESS capacity by 2030 (BMK, 2022).

In Czechia, grid-scale BESS is also expanding. As mentioned above, regulatory changes now allow BESS to participate in balancing markets, improving project economics (ČEPS, 2023).

Hydrogen storage is gaining momentum as a seasonal storage option. Austria's "Underground Sun Storage" and Czechia's hydrogen initiatives signal early

steps toward large-scale chemical energy storage (RAG Austria AG, 2021; Czech Ministry of Industry and Trade, 2024).
In summary, Europe’s energy storage market is diversifying: BESS is expanding rapidly for short-term flexibility and PHS is the key to long-duration balancing with hydrogen storage projects on the rise.

7. Policy Recommendations

To accelerate the adoption of long-term energy storage in the EU, Czech Republic, and Austria, several key recommendations can be made for governments, regulatory bodies, industry stakeholders, project developers, and the research community.

7.1. Policy Recommendations for Governments and Regulatory Bodies

Governments and regulatory bodies should implement targeted policies specifically designed to support the deployment of LTES technologies. This includes establishing clear financial incentives, such as direct subsidies, tax credits, and low-interest loans, as well as creating long-term revenue stability mechanisms like Contracts for Difference (CfD) and well-designed capacity markets (Starlinger & Götzinger, 2024). Streamlining the permitting processes and reducing administrative burdens associated with LTES projects are crucial steps to accelerate their development and deployment (European Commission et al., 2023). Market design flaws that currently disadvantage LTES, such as price caps and overly large minimum bid sizes for ancillary services, need to be addressed to create a more level playing field (Long Duration Energy Storage Council, 2023). Ensuring fair and non-discriminatory grid access for energy storage projects and eliminating double taxation and inconsistent grid tariffs are essential to improve their economic viability (Colthorpe, 2024). Setting clear and ambitious long-term targets for LTES deployment at both national and EU levels will provide the necessary signals to encourage investment and innovation in this sector (Long Duration Energy Storage Council, 2023). Finally, promoting the standardization of LDES systems can enhance interoperability, optimize cost structures, and ensure consistent quality and safety standards (Long Duration Energy Storage Council, 2023).

7.2. Recommendations for Industry Stakeholders and Project Developers

Industry stakeholders and project developers should prioritize innovation to enhance the efficiency, reduce the costs, and extend the lifespan of various LTES technologies (Colthorpe, 2025). Developing diverse portfolios of LTES technologies will be crucial for ensuring a resilient and secure supply chain, mitigating risks associated with reliance on single technologies or critical raw materials (Brown & Jones, 2024). Exploring the potential of hybrid energy storage solutions and the co-location of storage with renewable energy generation can lead to more efficient infrastructure utilization and streamlined permitting processes (EASE, 2022) Engaging proactively with local communities to address any concerns and enhance public acceptance of LTES projects is vital for their successful implementation. Furthermore, project developers should focus on developing robust business models that can leverage multiple revenue streams, including participation in ancillary services markets and wholesale energy trading (Janíček, 2025).

7.3. Recommendations for Research and Innovation

Increased investment in research and development is needed to advance the capabilities of various long-term energy storage technologies, including chemical, thermal, and mechanical storage solutions (European Commission et al., 2023). A key focus should be on developing LTES technologies that utilize low-cost and readily available raw materials to reduce dependence on critical minerals and enhance sustainability (Lozanova, 2025). Supporting pilot and demonstration projects is essential for validating the performance, reliability, and cost-effectiveness of emerging LTES technologies under real-world conditions (Janíček, 2025). Additionally, further research is needed to optimize the integration of LTES into the broader energy system, including its impact on grid stability, reliability, and overall system efficiency (Amsalem et al., o. J.; Lozanova, 2025).

8. Conclusion

Long-term energy storage systems are poised to play an increasingly vital role in the European Union's energy transition. Their ability to effectively integrate high penetrations of variable renewable energy sources, enhance grid stability and resilience, and contribute to energy security makes them indispensable for achieving the EU's ambitious climate and energy goals. The Czech Republic and Austria, while having distinct energy landscapes and deployment strategies, both recognize the crucial importance of LTES and are taking steps to foster its growth. While challenges related to cost, regulation, and infrastructure persist, the opportunities for innovation, investment, and policy support are significant. Continued commitment from governments, industry, and the research community is essential to accelerate the adoption of long-term energy storage technologies, paving the way for a secure, reliable, affordable, and deeply decarbonized energy future for the entire European Union. The transformative impact of LTES on the future European energy landscape promises a more sustainable and resilient energy system for generations to come.

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