Policy Options to Anticipate Europe’s Long-Duration Energy Storage Deployment

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Position Paper

Executive Summary

Europe's energy transition has entered a decisive phase. With renewable generation already exceeding 70% of supply in some Member States during certain hours or seasons, the core challenge is shifting from capacity expansion to system integration. This requires flexibility resources that can manage variability while maintaining reliability, and policy frameworks that accurately value assets capable of delivering extended firmness, fast response, and controllability under system stress.

Long-duration energy storage (LDES) is one of the solutions that can provide these capabilities, alongside other storage and flexibility resources. By storing renewable electricity over multi-hour to multi-day periods and dispatching it during supply shortfalls, LDES converts variable generation into firm, zero-emission supply. In doing so, it supports system reliability, reduces curtailment and external dependencies, improves congestion management and balancing efficiency, maximises renewable integration, and strengthens industrial competitiveness by enabling stable clean power for energy-intensive industries, electrified industrial processes, and large consumers such as data centres.

Despite its strategic value, long-duration energy storage remains marginal in many European Union planning and market frameworks. While some Member States are beginning to recognise its role—particularly within capacity mechanisms—current approaches often fail to distinguish between nominal duration and effective system contribution. As a result, LDES is frequently absent or underrepresented in key instruments such as National Energy and Climate Plans, resource adequacy assessments, and grid development plans, leading to systematic undervaluation of solutions that provide extended firmness and operational flexibility.

This lack of recognition reinforces investment barriers. The absence of predictable, long-term revenue frameworks for capital-intensive assets increases investor risk, especially for projects reliant on multi-service revenue streams. Procurement designs based on rigid duration thresholds rather than performance-based adequacy metrics further weaken bankability, raise the cost of capital, and slow deployment, increasing system costs and prolonging reliance on fossil backup capacity.

Europe therefore faces a strategic choice: continue relying primarily on conventional flexibility—accepting higher costs and volatility—or adopt a portfolio-based approach that recognises extended-duration, fast-responding, and highly controllable storage assets, alongside multi-day solutions, as critical energy infrastructure. Such an approach would strengthen security of supply and system resilience, enable efficient integration of high shares of renewables, and support Europe's clean industrial competitiveness over the long term.

This paper assesses the system value of long-duration energy storage, identifies the barriers to its deployment, reviews existing support options, and proposes recommendations to better align European energy, industrial, and financing frameworks with the long-term flexibility needs of a fully decarbonised power system, while ensuring technology-neutral recognition of firm contribution across storage durations and operating profiles.

Focus: The Questions this Paper Aims to Answer

1. What are long-duration energy storage technologies and which services do they provide?

2. What are the barriers preventing long-duration energy storage deployment in Europe today?

3. How do today's markets, planning, and modelling undervalue long-duration energy storage's contributions to the energy system?

4. What are options to procure long-duration energy storage, and what are their strengths and weaknesses?

5. What markets, regulatory frameworks, planning, and modelling are required to deliver cost-effective long-duration energy storage deployment?

Context: The Cost of Inaction

Persistent Curtailment and Higher-than-Optimal System Costs: JRC analysis indicates that, under a 2040 scenario, up to 310 TWh/year of renewable generation could be curtailed due to grid congestion, implying significant lost value and higher congestion management needs. Curtailment is not inherently inefficient: power system analysis shows that a limited, non-zero level can be cost-optimal where the cost of avoiding the last units of curtailment exceeds their value (Global Consortium, 2024.) However, persistent and large-scale curtailment increases balancing and redispatch requirements, weakens revenue adequacy for renewables, and drives reliance on out-of-market interventions. Long-duration energy storage (LDES) can reduce avoidable curtailment by shifting surplus generation to periods of scarcity and by providing flexibility during prolonged low-VRE conditions.

Greater Exposure to Multi-Day System Stress Events: ENTSO-E modelling indicates that multi-day periods of low wind and solar output will occur several times per year by 2030. In the absence of long-duration energy storage and other sources of flexibility, these events will be met with fossil reserve capacity, prolonging dependence on imported gas and increasing risks of price volatility or supply interventions.

Increased Grid Reinforcement Requirements and Delays: The Commission estimates investment needs of roughly €730 billion (distribution) and €477 billion (transmission) by 2040, reflecting the scale of the grid challenge. LDES can be strategically sited to provide congestion relief and peak reduction, and in specific locations it can function as a non-wires alternative that defers or reduces the timing and scale of network reinforcement, especially where constraints are driven by short periods of peak loading or local renewable export limits.

Missed Industrial and Data Centre Decarbonisation Opportunities: Behind-the-meter (BTM) long-duration energy storage deployment at industrial sites and data centre s can provide firm, low-cost renewable power for electrification and high-grade heat processes, enabling up to 8 billion tonnes of avoided industrial CO_2 emissions globally while supporting Europe's energy-intensive sectors. Without targeted behind-the-meter long-duration energy storage support, data centre electricity demand could surge 160% to 287 TWh by 2030—emitting 39 million tonnes of CO_2 annually from new facilities alone, equivalent to half of Germany's planned 2030 emissions cuts—while slowing industrial competitiveness and prolonging fossil fuel reliance in decarbonising processes like steel and cement production.

Underestimation of System Value Delays Deployment: Continued reliance on metrics such as levelised cost of energy (LCOE) and levelised cost of storage (LCOS) obscures the system value of long-duration energy storage. These metrics are one-dimensionally focused on cost and do not capture system benefits (including positive externalities) like firming capability that allows expanding the hedging markets, inertia contribution that makes up for the phase out of conventional fossil generation, seasonal balancing and avoided curtailment that optimise the need for additional renewables investments and reduce the dependence on fossil fuel imports, or efficiently deferred grid reinforcement. Without adapting cost-value assessment frameworks, planning processes will continue to undervalue LDES, not signalling the appropriateness of LDES investments even when it is the most efficient system option.

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List of Abbreviations

A-CAES – Adiabatic Compressed Air Energy Storage

ARENA – Australian Renewable Energy Agency

CapEx – Capital Expenditure

CAES – Compressed Air Energy Storage

CEF – Connecting Europe Facility

CF-PPA – Clean, Firm Power Purchase Agreement

CISAF – Clean Industrial Deal State Aid Framework

CPIH – Consumer Prices Index including owner-occupiers' housing costs

CRM – Capacity Remuneration Mechanism

DSO – Distribution System Operator

EIB – European Investment Bank

EMD – Electricity Market Design

ENTSO-E – European Network of Transmission System Operators for Electricity

ERAA – European Resource Adequacy Assessment

ETS – Emissions Trading System

EU – European Union

GWh – Gigawatt-hour

GW – Gigawatt

IRA – Inflation Reduction Act (United States)

LAES – Liquid Air Energy Storage

LDES – Long-Duration Energy Storage

LOLE – Loss of Load Expectation

MW – Megawatt

MWh – Megawatt-hour

NECP – National Energy and Climate Plan

NRAA – National Resource Adequacy Assessment

OpEx – Operating Expenditure

PCI – Project of Common Interest

PPA – Power Purchase Agreement

PHS – Pumped Storage Hydropower

RES – Renewable Energy Sources

RRF – Recovery and Resilience Facility

TEN-E – Trans-European Networks for Energy

TRL – Technology Readiness Level

TSO – Transmission System Operator

TYNDP – Ten-Year Network Development Plan

WACC – Weighted Average Cost of Capit

1. Introduction: Europe’s Flexibility Gap

During the 1970s and 1980s, in the wake of energy crises which focused attention on the need to increase system efficiency, European countries rapidly deployed pumped-storage hydropower (PHS). Spain, for example, expanded PHS to integrate inflexible nuclear generation. Nuclear plants operated as a stable baseload but could not adjust to daily demand fluctuations. PHS offered a solution—storing off-peak energy and releasing it during high demand—laying the groundwork for modern long-duration energy storage.

Today, Europe faces a similar challenge. Rapid growth in wind and solar, essential for decarbonisation and competitiveness, is driving unprecedented variability in power generation. With renewables already covering over 50% of electricity in some Member States, the EU’s goal of 80% renewable power by 2040 demands far greater system flexibility.

Analyses by the Joint Research Centre (JRC) and ENTSO-E indicate that Europe’s flexibility needs will double by the early 2030s, with a growing need for both extended multi-hour and multi-day balancing becoming indispensable to maintain adequacy and limit curtailment efficiently. ENTSO-E estimates 2–4 multi-day shortfalls per year, each lasting up to ten days across major Member States, often preceded and accompanied by prolonged periods of steep ramps, partial scarcity, and regional congestion where extended multi-hour flexibility plays a critical system role.

Recent market data illustrate this volatility. In 2023, over 12 TWh of renewable generation was curtailed in the EU—costing €4.3 billion in congestion management. Without intervention, this could reach 118 TWh/year by 2030, raising system costs to €95 billion annually.

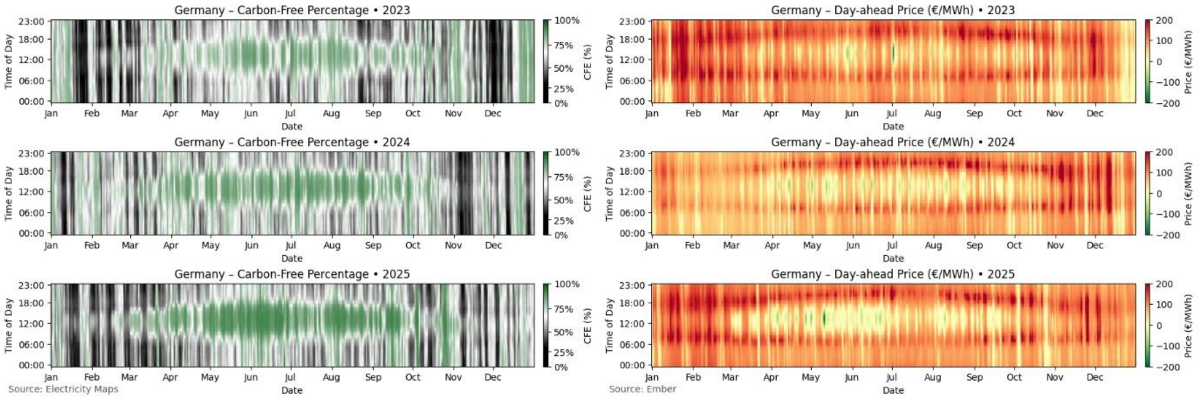


Figure 1: High midday renewable generation depresses prices, while other hours experience sustained volatility. Source: EnergyTag

As shown above, Germany’s price volatility and carbon-free share patterns reflect a growing mismatch between renewable supply and system flexibility. Summer midday prices are increasingly depressed by high solar output, while evening and winter peaks remain high. This pattern, replicated across Europe, erodes renewable profitability, raises balancing costs, and underscores the need for a portfolio of long-duration and extended-duration flexibility resources capable of addressing both ramping stress and sustained scarcity.

Long-duration energy storage—technologies capable of storing and releasing electricity for extended, multi-hour to multi-day durations along a continuum of duration and firmness —can bridge this gap. By providing clean, dispatchable capacity, LDES enhances reliability, limits curtailment, and supports industrial decarbonisation. Studies highlight its value:

- **Cost reduction:** 20 GW of LDES in the UK by 2035 could save £24 billion per year (DESNZ Research Paper, 2024).
- **Curtailment and congestion minimisation:** LDES could cut curtailment in Ireland's congested regions by 90%, saving €85 million annually (Baringa, 2022).

Beyond balancing, LDES can efficiently defer grid reinforcements, reduce fossil dependence, and enable clean power round-the-clock for industry. Yet despite these benefits, Europe lacks the clear investment signals now seen in the United Kingdom (Cap-and-Floor scheme), Australia (REZ framework, LTESAs, and the FERM model in South Australia), and several U.S. state tenders, particularly signals that consistently value duration, controllability, and system contribution across different storage technologies and operating profiles.

Planning and procurement frameworks must explicitly assess a range of storage durations, rather than relying on simplified or binary assumptions, as modelling shortcuts can later translate into structurally biased procurement outcomes.

Without dedicated LDES procurement and revenue frameworks, Europe risks missing a critical enabler of renewable integration and energy security. This paper explores how to close that gap by:

- Defining the role and characteristics of LDES;
- Identifying key financial, regulatory, and market barriers;
- Reviewing support instruments in Europe and abroad;
- Proposing policy actions to integrate LDES into EU and national frameworks.

2. Overview of LDES Solutions and Applications

There is currently no EU-wide, industry or policy-endorsed definition of long-duration energy storage. While several Member States apply national definitions, and international initiatives have proposed working formulations, a common European reference has yet to be established. For the purposes of this paper, Energy Storage Europe adopts the following working definition:

> **Long-duration energy storage (LDES) refers to a class of technologies capable of storing energy in chemical, electrochemical, mechanical, or thermal forms, and releasing electricity from multi-hour to multi-day, weekly, or seasonal durations.**
>
> LDES encompasses pumped hydropower storage (PHS), novel gravity-based systems, compressed air energy storage (CAES), liquid air energy storage (LAES), compressed gas energy storage (CGES), thermal storage in sensible, latent, or thermochemical form, electrochemical systems such as flow batteries and metal air batteries, and chemical storage through power-to-gas-to-power pathways, including hydrogen and synthetic fuels.

While power-to-heat (and cooling) and broader power-to-X applications also provide long-duration energy storage and play an important role in the energy transition, they fall outside the scope of this paper and are therefore not addressed.

The following sections describe the technical characteristics, applications, and system services of LDES technologies in the context of the electricity system.

2.1 Technical Characteristics

LDES technologies encompass a wide range of operating profiles, efficiencies, and design approaches. Their characteristics shape how they can be deployed in the system and determine the most suitable business models. In practice, storage assets are deployed across a spectrum of durations, all of which can deliver material system value depending on local grid conditions, system needs, and stress scenarios.

Category	Attribute	Range Across Technologies	System Implication
Performance	**Round-trip Efficiency**	• 30 % (Hydrogen) • 70-90 % (Flow batteries, CAES, GCES) • 85–87 % (PHS)	They can provide from intra-day arbitrage (8–24 h) to multi-day/seasonal services, especially when charged with curtailed/negative-priced RES
	Degradation Profile	Minimal	Low-degradation assets avoid augmentation, reduce O&M, and behave like conventional generation in long-term planning
	Cycling Profile	10 to >365 cycles/year	Low-cycle design matches availability contracts and capacity payments; optimal for rare, high-impact events (dunkelflaute, outages)
Design & Scalability	**Energy-to-Power (E/P) Ratio**	Highly variable; decoupled in mechanical/thermal systems as well as flow batteries	Enables independent scaling of duration vs. power → supports multi-day to seasonal applications without proportional CapEx.
	Long Asset Lifetime	15–80 years >50 years (PHS, CAES) with minimal replacement; 20-35 years for other LDES technologies	Long life = infrastructure-grade asset; reduces LCOE, supports 50+ year grid planning, and justifies large-scale (>500 MW) deployment
Strategic & Grid Integration	**Materials Availability**	No critical raw materials (PHS, CAES, iron-air, CGES); and well-established EU supply chains	Enhances EU strategic autonomy, reduces price volatility, and supports domestic manufacturing
	Grid-Forming & Ancillary Services	Yes (PHS, CAES, GCES with rotating mass) Yes (electrochemical storage equipped with grid-forming inverters, already deployed and procured in several European systems)	Provides inertia, black-start, voltage support — critical as fossil plants retire. Not yet fully remunerated in many EU markets
	Siting Flexibility	• **Low** (geology-dependent: greenfield PHS, some CAES, H_2 caverns) • **High** (electrochemical, modular mechanical, advanced-CAES, brownfield PHS)	Flexible siting enables congestion relief and industrial co-location. Geological constraints can be offset by lower CapEx and high system value

2.2 Applications and System Services

LDES delivers flexibility across different timeframes and supports a wide range of system needs. Its applications span intra-day balancing, multi-day firming, and seasonal storage, while its system contributions strengthen grid stability, resilience, and industrial decarbonisation. The tables below summarise these roles by timescale and system function.

Timescale-Based Applications:

Timescale	Application	Description
Intra-Day (8–24 h)	**Intra-Day Shifting**	Shifts excess solar/wind to evening peaks; supports solar/wind/demand ramps, reduces curtailment and balances daily load.
Multi-Day (Day-Week)	**Multi-Day Firming**	Sustains output during dunkelflaute; ensures reliability without fossil backup; significantly reduces resource requirements for decarbonised systems maximising renewable integration.
Seasonal (Month-Season)	**Seasonal Balancing**	Stores summer surplus for winter demand; addresses seasonal heating/electricity needs. PHS allows the management and storage of water flows from wet to dry seasons.

System Contributions:

System Contributions	Application	Description
Grid & Stability	**Congestion Relief**	Stores/dispatches locally to ease bottlenecks; defers grid upgrades. Supports energy-hubs, improve self-consumption of locally produced renewables.
	Ancillary Services	Stabilises frequency, voltage, and inertia in high-RES systems.
Resilience & Industry	**Islanded/Off-Grid**	Enables microgrids/remote areas during outages; enhances energy security.
	Industrial Decarbonisation	Supplies firm clean power to existing energy intensive industries and new industries willing to decarbonise based on electrification of their processes: steel, chemicals, data centres; enables round-the-clock carbon-free operations.

3. Barriers to Deployment and Uncertainty to Long-Duration Energy Storage

This chapter outlines four structural barriers that limit LDES deployment—modelling and planning, market design and regulation, financial and investment conditions, and permitting and grid access. These barriers increase project risk, slow investment decisions, and ultimately raise system-wide costs.

1) Modelling and Planning

Most national and EU planning frameworks remain “duration-blind.” Adequacy and system models often fail to evaluate least-cost resource mixes across different durations. This leads to sub-optimal pathways that overlook multi-day flexibility needs.

The absence of an EU-wide LDES definition—and the practice of measuring storage only in MW rather than MWh—further obscures the system value of long-duration assets and weakens procurement and planning signals.

2) Market and Regulation

Current market design often favours short-duration or narrowly defined flexibility solutions, driven by simplified modelling and procurement practices rather than system needs. As a result, long-duration energy storage is frequently undervalued: multi-hour and multi-day availability is rarely rewarded, scarcity pricing is inconsistent, and capacity mechanisms apply de-rating factors and contract terms that are misaligned with assets of longer duration.

Essential system services such as inertia, voltage control, and black start are not consistently procured or remunerated, while incentives for TSOs and DSOs to contract flexibility instead of grid reinforcement remain limited, slowing efficient LDES deployment.

3) Financial and Investment

LDES requires clear procurement signals and a credible pathway to scale to attract investor confidence. These signals are weak today in both market mechanisms (direct revenue visibility) and system planning (indirect certainty), resulting in higher perceived risk, higher cost of capital, and reduced debt leverage. Forward curves also underestimate future extreme price events (e.g. dunkelflaute).

Without long-term revenue-stabilisation tools, investment decisions are delayed or cancelled, particularly for capital-intensive projects with long development timelines

4) Permitting and Grid Access

LDES projects face lengthy, fragmented permitting processes that can extend 5–10 years. Fast-track procedures exist in legislation but remain unevenly implemented.

Grid access is constrained, with limited connection capacity and varying grid codes across Member States, adding engineering risk and extending delivery timelines. Where reinforcements are needed, delays further restrict LDES deployment despite its ability to relieve congestion and support renewable integration.

3.1 Modelling and Planning Barriers

European planning and adequacy frameworks remain largely duration-blind. While treating storage as a single category is not inherently an issue, current modelling does not evaluate the full range of flexibility options — particularly multi-day storage technologies. As a result, adequacy and network plans frequently overlook solutions capable of managing extended renewable droughts, relieving congestion for long periods, or providing firm capacity, which leads to incomplete assessments of system needs and sub-optimal investment decisions. These risks are exacerbated when capacity mechanisms rely on simplified duration classes inherited from planning models.

Barrier	Explanation	Implications
Under-representation in Planning and Adequacy Models	Resource adequacy assessments and capacity de-rating methodologies typically assume 1–4 hours discharge capability or 8 – 12 hours specific technologies.	System planning may overbuild renewables or grid assets, or rely longer on fossil backup (1 – 4h). Competitive technologies might be excluded due to rigid, long-term approaches (8 – 12h).
Lack of LDES understanding	Storage is often defined only in MW terms, without GWh duration or operational profile.	Procurement frameworks continue to favour short-duration flexibility, with limited recognition of sustained and multi-day delivery, even as adequacy assessments increasingly point to prolonged stress events.

3.2 Market and Regulation Barriers

Electricity markets and support scheme designs are oriented toward energy throughput and short-duration balancing, not long-duration availability. Capacity mechanisms, ancillary service markets, and price formation rules do not fully capture the value LDES provides during extended low-renewable periods or system stress.

Barrier	Explanation	Implications
Undervaluation of duration and adequacy contribution	Capacity mechanisms and related revenue models mainly reward 1–4-hour assets; LDES receives low de-rating factors and unsuitable lead-times and contract tenors.	As system conditions evolve, the absence of explicit recognition for sustained adequacy may delay investment in resources needed for future stress events, increasing reliance on conventional peaking solutions and raising long-term system costs.
Limited procurement of system services	Markets seldom procure inertia, voltage support, black-start capability, or long-duration reserve products.	While non-remuneration may be efficient in current market conditions, the lack of transparent valuation can weaken the business case for assets that could provide these services at lower system cost in future high-renewables systems.
Distorting taxation and tariff frameworks	Storage can face double charging and grid tariffs that do not reflect	LDES cannot monetise congestion relief or grid-support benefits; operational value remains under-rewarded.

	system value or provide temporal or locational signals.	
Missing flexibility signals for non-wire alternatives	TSOs and DSOs do not consistently assess flexibility solutions alongside grid reinforcement in planning processes. In practice, flexibility and network investments are often treated as complementary rather than directly comparable options.	LDES is not evaluated with traditional investments to choose the most cost-effective solution.
Lack of locational signals	Uniform pricing zones underpin equal access to electricity and legal certainty for consumers in several Member States. While this supports fairness and simplicity, it can limit the visibility of local congestion and flexibility needs.	Sub-optimal siting; rising redispatch costs; reduced deployment of LDES where most needed.
Untailored state-aid and support mechanisms	Auctions often rank projects purely on €/MW, without weighting duration, resilience, or system fit.	Short-duration assets crowd out LDES in support schemes; integration value is not recognised.

3.3 Financial and Investment Barriers

LDES technologies typically involve substantial upfront investment, longer development cycles, and revenue streams that are not yet fully established in European markets. As long-term remuneration frameworks continue to evolve, access to debt financing remains limited and investors face higher uncertainty. Strengthening predictable, multi-year revenue structures would significantly improve investment conditions and ease deployment.

Barrier	Explanation	Implications
High capital intensity and long investment horizon	CAPEX can range from €1,000–1,500/kW for mature technologies and significantly higher for emerging ones. Development cycles span 5–10 years before revenue begins.	Higher cost of capital, increased exposure to long-term market uncertainty, and a greater likelihood of delayed or cancelled investment.
Uncertain revenue streams	LDES derives value from rare multi-day scarcity events, but markets remunerate short-duration cycling, and scarcity pricing is inconsistent.	Projects are not bankable without long-term revenue stabilisation tools (e.g. CRMs, cap-and-floor, availability contracts).
Uneven access to capital across technologies	Mature LDES technologies can secure institutional financing; emerging technologies lack operational track records.	Higher risk premiums and lower leverage for emerging technologies slow scale-up, cost reduction, and diversification of the LDES portfolio.

3.4 Permitting and Grid Access Barriers

Permitting and grid access remain significant sources of delay for LDES projects. Existing administrative and connection frameworks were developed before the emergence of today's diverse storage landscape, and many procedures do not yet fully reflect the range of technologies, siting profiles, or operational characteristics now available. As a result, LDES projects often navigate processes that were not designed with their specific configurations in mind, which can lengthen development timelines and add uncertainty.

3.4.1 Permitting Barriers

Barrier	Explanation	Implications
Lengthy and fragmented permitting	Multiple authorities and limited coordination can result in 5–10-year timelines. Acceleration areas and fast-track procedures are unevenly implemented.	Higher financing costs and delayed final investment decision; LDES often assessed under frameworks designed for Li-ion despite lower risk profiles. *Recent EU reforms aim to address these barriers. The Grids Package and the revised Directive on permitting of energy infrastructure now introduce binding deadlines of six months for standalone energy storage above 100 kW and up to two years for pumped hydropower.*
Inconsistent treatment across technologies	Longer-duration technologies often face more extensive environmental assessments than other technologies.	Unlevel playing field; delayed deployment of first-of-a-kind or low-risk LDES.
Limited institutional capacity	Many authorities lack expertise in storage technologies, hybrid RES+storage projects, and fire safety.	Slower, inconsistent decisions; increased compliance burdens.
Disproportionate environmental impact assessments	Storage frequently triggers full EIAs even when risk profiles do not justify them.	Years of delay; retrofits of industrial sites require full reassessment.
Local opposition and unclear zoning	Projects face objections or duplicative safety requirements even when compliant.	Adds uncertainty, increases soft costs, and slows deployment in optimal industrial zones.

For further detail, see Energy Storage Europe's Position Paper on Improving Permitting Procedures.

3.4.2 Grid Access Barriers

Barrier	Explanation	Implications
Connection queue constraints	Although the tendance is changing, first-come-first-served queues without readiness filters	Ready-to-build LDES is delayed; curtailment and congestion relief are deferred.

	still allow inactive projects to block capacity.	
Insufficient or delayed grid reinforcement	Network expansion is slow; LDES is not systematically considered as a non-wire alternative.	Suboptimal siting and missed opportunities for grid deferral.
Limited implementation of simplified or fast-track procedures	RED III and TEN-E fast-track provisions are rarely applied to storage.	Strategic LDES near constrained nodes or industrial clusters face unnecessary delays.
Inconsistent and outdated grid codes	Requirements often reflect synchronous generation or Li-ion behaviour rather than long-duration flexibility.	Higher engineering risk and longer design cycles; cross-border projects become more complex.
Limited transparency from TSOs/DSOs	Few Member States publish hosting capacity maps, connection data, or queue transparency.	Developers cannot identify optimal locations; uncertainty raises development costs.

For further detail, see Energy Storage Europe’s Position Paper on Grid Connections.

4. Options to Procure Long-Duration Energy Storage in Europe

The preceding chapter identified the structural barriers that currently limit LDES deployment. This chapter sets out the policy instruments, procurement models, and market design reforms that can address these constraints and enable deployment at scale.

The instruments are grouped according to the primary constraint they address, following the logical sequence from system planning to markets, finance, and delivery:

- **Modelling and Planning –** integrating LDES into national and EU planning frameworks, with clear definitions, modelling practices, and needs assessments that reflect multi-day system requirements.
- **Market and Regulation –** aligning market design with the value of multi-hour and multi-day flexibility, so that LDES is remunerated for adequacy, system stability, and congestion relief.
- **Financial and Investment –** improving bankability by stabilising revenues, lowering the cost of capital, and enabling early-stage projects to reach final investment decisions.
- **Permitting and Grid Access –** accelerating project development through streamlined procedures, stronger institutional capacity, digital queues, and anticipatory grid investments.

All interventions should be designed to complement, not distort, the functioning of European electricity markets. Where direct procurement or support schemes are required, they should respond to clearly defined system needs, preserve efficient price signals, and be subject to careful design and consultation to minimise unintended distortions.

4.1 Instruments to Improve Modelling and Planning

These tools strengthen the visibility of longer-duration flexibility needs across adequacy, flexibility, and network planning processes. They provide clear signals on required volumes, durations, and locations by ensuring LDES is assessed on equal footing with other system options. This supports more accurate stress-testing, targeted procurement, and efficient infrastructure planning.

4.1.1 Resource Adequacy Assessments

European Resource Adequacy Assessments (ERAA) and National Resource Adequacy Assessments (NRAAs) currently undervalue long-duration flexibility by modelling most storage as short-duration resources. This limits visibility of multi-day adequacy risks and affects Member States' ability to justify appropriate procurement tools, including capacity mechanisms.

Strengthening the treatment of longer-duration storage in ERAA and NRAAs—by moving from static duration-based adequacy crediting to probabilistic, scenario-based approaches that reflect effective firm energy delivery during realistic stress events—would improve visibility of multi-day adequacy risks and support better-targeted national procurement measures.

STRENGTHS	**WEAKNESSES**
Improves visibility of multi-day adequacy needs	Requires enhanced modelling tools
Supports Member States' CM design and fast-track approval	Risk of over-reliance if poorly calibrated
Aligns with ERAA reform objectives on flexible resource modelling	Needs harmonised data inputs

Case Study: ENTSO-E ERAA 2024 – Flexibility Module (Pilot)

First ERAA to model weekly flexibility; identifies 2–4 multi-day shortfalls/year by 2030. Pilot credits ≥8h storage at 100% during 7-day events. Full integration planned for ERAA 2026.

Actor Involvement

Actor	Involvement	Role
EU	✓	Mandates ERAA updates under EMD Reform and supports CM streamlining
EIB	✓	Finances TSO modelling upgrades
Member States	✓	Aligns NRAA with ERAA outputs
System operators	✓	Develops stress scenarios; procure LDES
Industries	✓	Validates industrial load profiles
Developers	✓	Supplies performance data

4.1.2 Flexibility Needs Assessment

Flexibility Needs Assessments (FNAs) must distinguish long-duration storage from short-duration technologies to reflect their different roles, operating profiles, and system value. This granularity is essential to quantify multi-day flexibility needs, identify gaps that market-based deployment will not fill, and ensure LDES is eligible for remuneration across all relevant services (flexibility across timeframes, frequency response, black-start capability, and sustained delivery during prolonged low-renewable periods). Without such detail, Member States risk prioritising solutions that cannot address the ≥8–10-hour storage gap emerging across Europe.

FNAs may also trigger direct procurement when markets cannot deliver the required volume or duration of flexibility. Although the Clean Industrial Dial State Aid Framework (CISAF) provides a basic framework for such tenders, its focus on selecting the cheapest MW is insufficient for LDES, whose value depends on duration, operability, cycling capability, and location. Any future auction derived from FNAs should therefore apply criteria to ensure procurement targets assets that maximise system value and reduce long-term costs.

STRENGTHS	**WEAKNESSES**
Provides granular, location-specific flexibility roadmaps	Requires significant data integration across TSOs/DSOs
Justifies LDES procurement with cost-benefit analysis	Risk of underestimating demand-side flexibility
Enables anticipatory grid planning	High analytical complexity

Case Study: Great Britain – Future Energy Scenarios Flexibility Assessment (2024)

National Grid ESO's Future Energy Scenarios 2025 acknowledges the importance of extended flexibility in managing multi-day low wind and solar periods. While deployment forecasts for long-duration storage are lower in the near term—revised to 3–5.3 GW by 2030 due to long lead times and capital costs—projected ranges expand to 13–17 GW by 2050, underscoring the enduring system value of sustained flexibility even where capacity expansion in the 2030s is moderated.

Actor Involvement

Actor	Involvement	Role
EU	✓	Encourages via Network Code on Demand-Side Flexibility
EIB	✓	Funds joint TSO-DSO assessment platforms
Member States	✓	Mandates national FNAs in law
System operators	✓	Leads modelling; define procurement zones
Industries	✓	Provides demand response and electrification forecasts
Developers	✓	Inputs technology cost curves and performance

4.1.3 Ten-Year Network Development Plan

The Ten-Year Network Development Plan (TYNDP) is Europe's central planning instrument for identifying long-term transmission and system-flexibility needs. Including LDES within the TYNDP ensures storage is assessed alongside conventional grid reinforcements using the established cost–benefit analysis methodology. This allows TSOs to model when storage offers a more efficient alternative to new infrastructure and to incorporate multi-day flexibility into cross-border scenario development.

A dedicated LDES layer in the TYNDP highlights optimal locations, quantifies system value, and provides a structured basis for prioritising long-duration flexibility in future network development. This improves visibility of storage as a planning option and creates a coherent, cross-border view of where LDES can deliver the greatest system benefit.

STRENGTHS	WEAKNESSES
Integrates LDES into long-term EU system planning	Dependent on TSO sponsorship and biennial cycle
Quantifies grid deferral value through harmonised CBA	Requires consistent modelling inputs across countries
Supports coordinated cross-border planning	Long development timelines limit short-term impact

Case Study: TYNDP 2024 – LDES as Non-wire Alternative

The 2024 TYNDP included 42 LDES projects (total 18 GW/250 GWh) in the optimal expansion plan for 2030, avoiding €12 billion in transmission investments by 2035. Three projects—PHS in Spain, CAES in Germany, and flow batteries in Italy—achieved PCI status and received €180 million in CEF grants, with fast-track permitting reducing timelines from 7 years to 3 years.

Actor Involvement

Actor	Involvement	Role
EU	✓	Approves TYNDP and provides CEF alignment
EIB	✗	-
Member States	✓	Nominates national LDES candidates
System operators	✓	Integrates LDES into scenario modelling and CBA
Industries	✗	-
Developers	✓	Provides project data and cost assumptions

4.1.4 Distribution Network Development Plan

The DNDP provides a structured assessment of local grid constraints and future flexibility needs at distribution level. Integrating LDES into these plans ensures DSOs can evaluate storage as a non-wire alternative to traditional reinforcement, using comparable cost and performance criteria. This enables more accurate local adequacy assessments, supports coordinated hybrid RES–storage planning, and highlights where multi-hour flexibility can alleviate congestion or defer infrastructure upgrades.

Incorporating LDES into DNDP processes strengthens bottom-up system visibility and creates a pipeline of locations where storage can deliver high value, informing both national planning and potential future procurement exercises.

STRENGTHS	WEAKNESSES
Targets high-value congestion areas with granular data	Fragmented across many DSOs
Improves local system planning and hybrid project integration	Requires regulatory empowerment and guidance
Enables more efficient investment decisions	Limited balance sheet capacity in some DSOs

Case Study: GB DSOs – Local Flexibility Tenders (SSEN and UK Power Networks)

In 2023–2024, Scottish and Southern Electricity Networks (SSEN) Distribution contracted over 700 MW of flexibility services through two additional bidding rounds in its licence areas in central southern England and north of Scotland, following Distribution Options Assessments that identified where flexibility could efficiently relieve constraints. In parallel, UK Power Networks awarded contracts for 327 MW of flexibility across 127 sites to 17 providers, expanding its local flexibility market and using the services as an alternative to or to defer traditional reinforcement in defined “constraint-managed zones”.

Actor Involvement

Actor	Involvement	Role
EU	✓	Provides harmonisation via DSO Entity
EIB	✗	—
Member States	✓	Mandates LDES in national DNDP rules
System operators	✓	Leads local tenders; model congestion
Industries	✗	—
Developers	✓	Provides load profiles and technical data

4.2 Instruments to Mitigate Market and Regulation Barriers

These instruments address market design and regulatory rules to enable LDES to receive appropriate remuneration for multi-hour and multi-day contributions to adequacy, system stability, and congestion management. They address gaps in de-rating methodologies and system-service procurement frameworks, ensuring that LDES is compensated for the services it provides while maintaining competitive and technology-neutral market operation.

4.2.1 Duration-Aware Capacity Markets

Duration-aware capacity mechanisms remunerate resources based on their effective contribution to system adequacy during scarcity events, rather than availability alone. This requires moving beyond designs that implicitly favour short delivery periods.

In line with the Clean Industrial State Aid Framework (CISAF), de-rating factors should adjust installed capacity to reflect actual adequacy contribution, accounting for technology characteristics, reliability, and bidding-zone conditions. Where available, de-rating should rely on ERAA outputs published by ACER and ENTSO-E; in the interim, it should reflect availability during scarcity relative to installed capacity, updated regularly.

For long-duration energy storage, this approach shall enable adequacy crediting that reflects both power (GW) and usable energy (GWh), capturing sustained delivery and operational flexibility without relying on rigid duration thresholds. Appropriate contract lengths (15–20 years) can further improve bankability and allow LDES to compete fairly with low-CAPEX thermal capacity. Additional design improvements include allowing projects to propose their own de-rating factor—subject to penalties for non-performance—and, as explored in the UK Review of Electricity Market Arrangements Consultation Document, auction formats with multiple clearing prices to reward desirable system characteristics.

STRENGTHS	**WEAKNESSES**
Rewards multi-day firming capability	Requires reform of existing CRMs
Improves adequacy modelling and system reliability	Risk of biased outcomes if modelling relies on simplified duration assumptions
Enables LDES to compete with gas peakers	Increased administrative and design complexity

Case Study: Italy - MACSE scheme

Italy's Mercato della Capacità di Stoccaggio Elettrico (MACSE) is a dedicated capacity procurement mechanism for electricity storage, designed to support system adequacy through long-term contracts. While it reflects a duration-aware approach, adequacy modelling and procurement have relied on a limited set of predefined storage durations, largely for modelling simplicity. This illustrates how simplified planning assumptions can translate into procurement design and risk excluding storage configurations that could deliver equivalent system value.

Actor Involvement

Actor	Involvement	Role
EU	✓	Issues guidance
EIB	✗	—
Member States	✓	Designs and reform national capacity remuneration mechanisms

System operators	✓	Sets duration-based stress scenarios
Industries	✗	—
Developers	✓	Certifies duration capability

By stabilising long-term revenues, duration-aware capacity mechanisms also operate as a financing-enabling instrument for LDES and therefore also fall within the scope of Section 4.3.

4.2.2 Ancillary Services and Stability Markets

Ancillary and stability services are increasingly important in high-renewables systems. While services such as **inertia, voltage control, black start, and reserves** are already provided—and in some cases remunerated—current arrangements are often bilateral or technology-specific rather than open and scalable. For example, in France, several stability services are procured through specific TSO contracts, primarily from incumbent providers.

Some LDES technologies can deliver these services inherently, and non-remuneration may be efficient where system needs are limited. However, as system requirements evolve, more transparent and performance-based procurement will be needed to allow capable resources, including LDES, to compete on equal terms and deliver stability services at least cost.

STRENGTHS	**WEAKNESSES**
Monetises stability and system-strength value	Requires updates to grid codes and certification
Supports retirement of fossil synchronous assets	Market volumes remain limited in some Member States
Improves system resilience during stress events	Product design and verification can be complex

Case Study: Great Britain – Market-Based Inertia Procurement

Great Britain's system operator (NESO) has created a market-based framework for procuring inertia through its Stability Pathfinder programme and annual Stability Market auctions. Grid-code reforms enabled a technology-neutral approach where synchronous condensers, PHS, and grid-forming BESS compete to deliver inertia and system-strength services. Between 2020 and 2023, NESO awarded over £1.9 billion in contracts securing more than 36 GW·s of inertia, while the first auction for 2025/26 procured 5 GW·s at £25.3 million. The model enabled Europe's first transmission-connected grid-forming BESS at Blackhillock (300 MW / 600 MWh), providing synthetic inertia and voltage support under performance-based contracts and expected to deliver £170 million in consumer benefits over 15 years.

Actor Involvement

Actor	Involvement	Role
EU	✓	Sets framework conditions
EIB	✗	—
Member States	✓	Launches and regulate national tenders
System Operators	✓	Defines products, certifies performance, and procures services
Industries	✓	Potential providers of system-strength technologies
Developers	✓	Certifies grid-forming or synchronous capabilities

4.2.3 Grid Fee Reform

In many Member States, tariff structures were designed for uni-directional flows and do not recognise the system benefits storage provides, such as congestion relief, grid deferral, and balancing. As a result, storage can face double charging—network fees during charging and again during discharge—or tariff classifications that do not reflect its system role.

Reform should ensure that tariffs applied to storage are cost-reflective, transparent, and technology-neutral, distinguishing between actions that alleviate or worsen grid stress. Fair treatment of injection and withdrawal, along with predictable tariff methodologies, improves the business case for storage and aligns operation with system value.

STRENGTHS	WEAKNESSES
Improves operational efficiency and arbitrage value	Requires coordination between NRAs, TSOs and DSOs
Supports cost-reflective system operation	May shift cost allocation among user groups
Enables storage to provide more efficient congestion relief and grid services	Reform is administratively complex

Case Study: Denmark – Transmission Tariff Structure

Denmark applies time-differentiated transmission tariffs set by Energinet, where withdrawal tariffs vary by season and time of day to reflect system costs, while injection tariffs at the transmission level are set to zero, ensuring non-discriminatory treatment of storage and other flexibility resources. This framework, overseen by the Danish Energy Agency, aligns with EU requirements on cost-reflective network tariffs and supports efficient operation of storage without imposing double charging. Energinet and DSOs also operate ongoing flexibility pilots to test congestion-driven tariffs at distribution level, providing practical insights into tariff structures that better integrate storage.

Actor Involvement

Actor	Involvement	Role
EU	✓	Enforces non-discriminatory network tariff principles (EMD Article 18)
EIB	✗	—
Member States	✓	Implement tariff reform; mandate cost-reflective methodologies
System Operators	✓	Provide grid data; develop cost-reflective tariff structures
Industries	✗	—
Developers	✓	Provide operational data to inform tariff calibration
NRAAs	✓	Designs or approves tariff structures

4.3 Instruments to Mitigate Financial and Investment Barriers

These mechanisms reduce investment risk and improve bankability for capital-intensive LDES assets with long development cycles and uncertain revenue visibility. By lowering the cost of capital, stabilising long-term cash flows, and improving access to debt, they enable early projects to reach final investment decision and support the scale-up of diverse LDES technologies.

4.3.1 Financial Guarantees

First-loss guarantees from public institutions (typically 10–20% of principal) reduce lender exposure and allow projects to secure higher debt ratios at lower interest rates. They are particularly useful for early commercial LDES projects whose long-term revenue stack remains uncertain. Guarantees improve creditworthiness without requiring immediate fiscal outlay.

STRENGTHS	WEAKNESSES
Reduces perceived risk and lowers interest rates	Coverage remains limited and cannot support unviable projects
Unlocks commercial lending and higher leverage	Requires rigorous due diligence and monitoring
Replicable across Member States and portfolios	Potential moral hazard if poorly designed

Case Study

No LDES-specific guarantee has yet been issued, but EIF/EIB guarantee schemes for renewable infrastructure illustrate how risk-mitigation structures can mobilise commercial capital.

Actor Involvement

Actor	Involvement	Role
EU	✓	Funds EIF/EIB guarantee windows
EIB	✓	Co-issues guarantees and screens project risk
Member States	✓	Establishes national guarantee schemes
System Operators	✗	—
Industries	✗	—
Developers	✓	Beneficiaries; complies with requirements

4.3.2 Grants under the Clean Industrial Deal State Aid Framework (CISAF)

Clean Industrial Deal State Aid Framework (CISAF) enables Member States to provide direct CAPEX support for storage technologies, including thermal and electricity-based LDES. Grants can cover up to 100% of eligible costs in competitive procedures or up to 45% through administrative allocation. These measures are well suited to first-of-a-kind or early commercial projects requiring high upfront investment. CISAF also allows support for non-fossil flexibility, creating an explicit pathway for LDES when linked to system needs or industrial decarbonisation.

STRENGTHS	WEAKNESSES
Reduces upfront capital costs immediately	Risk of over-subsidisation
Supports early commercialisation and FOAK deployment	State-aid ceilings may limit scope
Straightforward for Member States to implement	Does not provide long-term revenue certainty

Case Study: Spain – ERDF Support for Long-Duration Energy Storage

Spain's final European Regional Development Fund (ERDF)-cofinanced storage tender awarded funding to several high-energy storage projects with long discharge durations. Winner projects include Rolwind's ST Palmosilla (200 MW / 885 MWh) and ST Cerrillo (77 MW / 340 MWh), both designed to deliver multi-hour system flexibility beyond peak-shaving use cases. The awarded portfolio also contains storage projects developed by utilities with relatively high energy-to-power ratios, illustrating the use of investment grants for storage applications with longer discharge profiles.

Actor Involvement

Actor	Involvement	Role
EU	✓	Sets and approves national State aid schemes
EIB	✓	Co-finances projects alongside grants; provides technical and financial due diligence
Member States	✓	Designs and administers grant schemes
System Operators	✗	—
Industries	✗	—
Developers	✓	Applies for support and meet additionality criteria

4.3.3 Tax Credits and Concessional Loans

Tax credits reduce upfront investment costs through either investment tax credits (30–50% of eligible CapEx) or accelerated depreciation (5–7 years instead of 20–40), lowering net capital cost by 15–25% and improving early cash flow. They are particularly relevant for electrochemical or modular LDES solutions with front-loaded expenditures.

Concessional loans—offered at 1–3% versus 5–7% commercially—can come from the EIB, national promotional banks, or other financing facilities. Covering 40–70% of CapEx with 15–25-year tenors and construction grace periods, they reduce annual debt service by 20–30% and improve investment viability for technologies with partial or stochastic revenue streams (e.g., CAES or thermal storage).

Combined (e.g., a 40% ITC plus a 50% concessional loan), they can reduce WACC to under 5%.

STRENGTHS	WEAKNESSES
Improves project economics without direct grants	Improves project economics without direct grants
Tax credits benefit only profitable entities	Tax credits benefit only profitable entities
Scalable and compatible with private finance	Scalable and compatible with private finance

Case Study: U.S. Inflation Reduction Act (IRA) – Investment Tax Credit (ITC)

The IRA provides 30–50% ITCs to standalone storage. Emerging EU analogues include accelerated depreciation and national tax-credit pilots (e.g., Italy's 2025 LDES co-location credit).

Actor Involvement

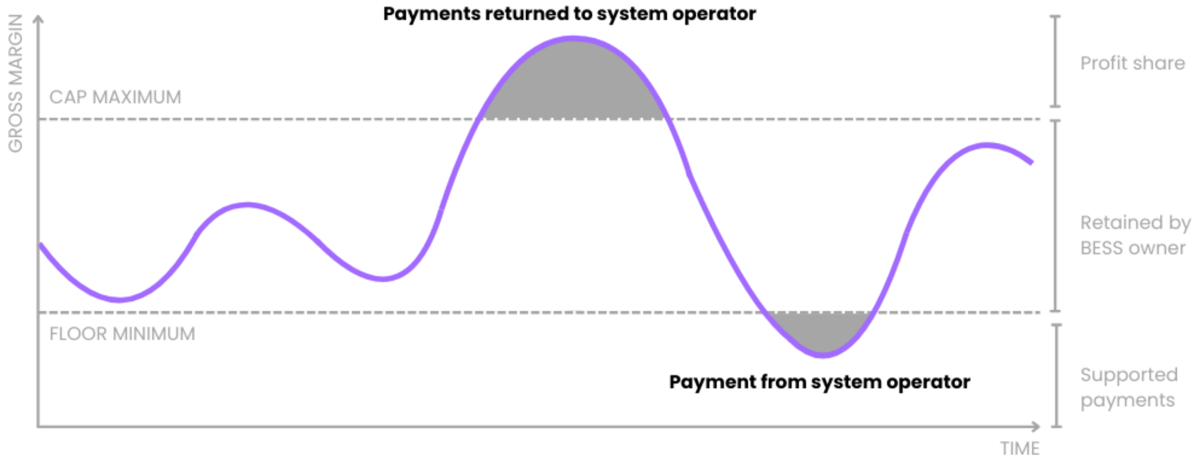
Actor	Involvement	Role
EU	✓	Sets compatibility rules
EIB	✓	Provides tax credits and concessional loan facilities
Member States	✓	Launches national calls
System Operators	✗	—

Industries	✗	—
Developers	✓	Submits claims for credits and loan applications

4.3.4 Cap-and-Floor Mechanisms

A cap-and-floor mechanism provides long-term revenue stability by limiting downside risk while retaining exposure to market prices. Floors are typically calibrated to cover fixed costs, debt service, and a reasonable return, enabling investment-grade cash flows over 15–25 years and high debt leverage. This makes the model well suited to capital-intensive LDES, while other storage and flexibility technologies may be better supported through capacity mechanisms, ancillary services, or locational tenders.

Careful scheme design remains essential. Rigid eligibility criteria and weak coordination with capacity markets can create risks of competition distortion and unintended price impacts, reinforcing the importance of performance-based and system-coherent implementation.



Source: Invinity Energy Systems

STRENGTHS	WEAKNESSES
Provides long-term, predictable revenues that improve bankability for capital-intensive LDES.	Requires careful calibration and sophisticated regulatory design.
Limits downside risk while maintaining exposure to market signals, protecting consumers from excessive returns.	Risk of competition distortion if eligibility rules are rigid or poorly aligned with system needs.
Supports long asset lifetimes and enables high levels of debt financing.	Potential unintended interactions with capacity and flexibility markets if revenue streams are not coordinated.

Case Study: UK – LDES Cap-and-Floor (2024–2025)

Ofgem introduced the first cap-and-floor specifically for long-duration storage, offering 25-year indexed revenue bands. Early interest from flow battery and CAES developers indicates strong suitability for LDES.

Actor Involvement

Actor	Involvement	Role
EU	✗	—
EIB	✓	May provide complementary guarantees
Member States	✓	Designs national schemes
System Operators	✓	Validates system need and asset performance
Industries	✗	—
Developers	✓	Participate and meet KPIs

4.3.5 Energy Storage Taxation Reform

Taxation rules for energy storage remain inconsistent across Member States, with several jurisdictions still applying taxes twice—once when storage charges and again when electricity is discharged and finally consumed. These practices do not reflect the actual role storage plays—shifting energy in time—and can discourage investment in technologies that support system flexibility.

Energy Taxation Directive (ETD) reform shall ensure taxation frameworks apply clear, technology-neutral rules, avoid treating storage as final demand when electricity is not consumed, and align with non-discrimination principles under the Electricity Market Design. This supports value-stacking, improves revenue predictability, and removes unnecessary financial barriers across all storage technologies.

STRENGTHS	WEAKNESSES
Reduces avoidable operating costs	May require revision of national tax codes
Ensures consistent, technology-neutral treatment	Coordination needed across ministries
Improves investment visibility	Potential political sensitivity around tax exemptions

Case Study: Romania – Removal of Double Taxation for Stored Electricity (2024–2025)

Romania eliminated double charging for stored electricity through GEO 134/2024 and ANRE's implementing Order of 8 July 2025. Storage operators are now exempt from transmission extraction tariffs, distribution tariffs, system services charges, green certificate obligations, and the cogeneration levy when electricity is stored and reinjected into the grid. The reform also redefines stored energy as not final consumption, aligning national rules with EU non-discrimination principles and ACER guidance. This modernised framework removes a major financial barrier and supports investment in storage technologies.

For a detailed assessment of double charging practices across European electricity markets, see EMMES 9.0.

Actor Involvement

Actor	Involvement	Role
EU	✓	Provides guidance under EMD; ensures non-discriminatory taxation principles
EIB	✗	—
Member States	✓	Reform national tax codes; clarify storage taxation categories
System Operators	✗	—

Industries	✗	—
Developers	✓	Demonstrate operational profiles to support fair tax treatment

For further detail, see Energy Storage Europe Reply to the European Commission Public Consultation on the Revision of the Energy Taxation Directive.

4.4 Instruments to Mitigate Permitting and Grid Access Barriers

These measures accelerate administrative processes and improve connectivity for LDES projects. They enhance permitting capacity, streamline procedures, and modernise grid-connection frameworks to ensure developers can secure timely approvals and access grid capacity in locations where storage provides the highest system value. They complement EU-level reforms on permitting and grid integration and support more predictable project delivery timelines.

4.4.1 Technology-Neutral Fast-Track Permitting Frameworks

Several Member States have introduced fast-track permitting for specific energy storage technologies—most commonly lithium-ion BESS—allowing projects to progress from concept to ready-to-build within months. While highly effective at accelerating deployment, these frameworks often exclude LDES technologies, even when they pose equal or lower environmental and safety risks. Establishing technology-neutral fast-track procedures ensures consistent treatment, reduces administrative burden, and removes unintended barriers to innovative or emerging LDES solutions.

A technology-neutral approach requires clear regulatory criteria, standardised environmental screening, and predefined safety requirements that apply proportionately across storage technologies. This ensures that innovative LDES projects are not forced into longer, more complex procedures designed for unrelated industrial assets.

STRENGTHS	**WEAKNESSES**
Eases deployment by providing predictable, streamlined pathways	Requires regulatory updates and harmonisation across authorities
Ensures equal treatment of all storage technologies	Potential resistance from authorities unfamiliar with LDES
Reduces administrative ambiguity for innovative systems therefore supporting early-stage commercialisation of LDES	Risk of misclassification if criteria are not well defined

Case Example: Italy – Extension of Fast-Track Permitting to LDES

Italy's fast-track regime for lithium-ion BESS has enabled more than 2.1 GW of capacity to move forward in 2024 alone. However, LDES technologies initially lacked a defined permitting pathway, leading to procedural delays despite comparable safety and environmental profiles.

Through structured engagement with national authorities, and the Sardinia Region, Italy implemented a technology-neutral interpretation: innovative LDES (including CO_2-based storage) can follow the same streamlined process as BESS. Authorities conducted detailed safety and environmental assessments and confirmed no significant risks, approving the project under the simplified procedure. This sets an important precedent for other Member States.

Actor Involvement

Actor	Involvement	Role
EU	✗	—
Member States	✓	Define technology-neutral categories; adopt streamlined procedures
Regional Authorities	✓	Conduct environmental and safety screening
System Operators	✗	—
Developers	✓	Provide technical documentation demonstrating compliance
Industries	✗	—
EU	✗	—

4.4.2 Skilled Workforce and One-Stop-Shop Permitting Coordination

Permitting delays frequently stem from under-resourced permitting bodies and limited technical knowledge of storage technologies. Fragmented procedures also create unnecessary dependencies (e.g., grid connection approvals required before environmental assessments or participation in capacity mechanisms). Strengthening administrative capacity through EU-funded training and establishing national one-stop-shops that coordinate environmental, grid and market-access permit in parallel would significantly shorten timelines. Digital twin tools can enhance consistency and reduce procedural uncertainty.

STRENGTHS	**WEAKNESSES**
Reduces permitting delays by ≈50% via parallel processing	Dependent on Member State commitment
Builds internal (TSO/NRA) technical expertise on storage	Requires upfront training and digital tools
Supports consistent value-stacking approvals	Initial digital platform investment

Case Study: Spain – One-Stop-Shop (RAAIP) and Digital Permitting for Energy Projects

Spain introduced a national one-stop-shop framework for energy infrastructure under Royal Decree-Law 23/2020, consolidating environmental, grid-access, and construction permits under coordinated authorities. Between 2021 and 2025, the Ministry for Ecological Transition (MITECO) expanded staff capacity and deployed digital tools for parallel processing, reducing duplication across agencies. Government reporting shows permitting times for grid-connected projects—including utility-scale storage and hybrid RES-storage facilities—fell by 30–50% depending on regional implementation. The reform improved coordination with the TSO and simplified environmental screening, creating predictable permitting pathways for innovative storage technologies.

Actor Involvement

Actor	Involvement	Role
EU	✓	Funds via CEF/Recovery Facility
EIB	✓	Blends with concessional loans
Member States	✓	Establish one-stop-shops

System Operators	✓	Provide grid impact data
Industries	✗	Sponsor training for co-located sites
Developers	✓	Supply standardised impact models

4.4.3 PCI and PMI Fast-Track Permitting with Binding National Rollout

Projects of Common Interest and Projects of Mutual Interest receive accelerated permitting under TEN-E, with a 3.5-year maximum timeline and priority status. Implementation remains uneven across Member States, where regional and local permitting delays often erode the intended acceleration. Strengthening compliance through one-stop-shop authorities, harmonised procedures, and pre-defined environmental corridors would make the framework fully effective for storage assets delivering major system value (e.g., adequacy, grid-deferral, cross-border benefits). Binding timelines are essential to turn PCI and PMI status into a real fast-track pathway.

STRENGTHS	**WEAKNESSES**
Cuts permitting from 5–10 to <3.5 years	Requires legislative and administrative change in many Member States
Unlocks PCI and PMI funding pipeline	Risk of local opposition
Proven in large cross-border infrastructure (e.g., HVDC interconnectors)	Limited to PCI and PMI-eligibility criteria

Case Study: Zero Terrain Paldiski – Underground Pumped Hydro PCI (Estonia)

The Zero Terrain Paldiski project is a PCI-listed underground pumped-hydro storage facility in Estonia capable of delivering up to 30 hours of storage. By using subsurface reservoirs instead of mountain-based topology, it demonstrates how large-scale LDES can be deployed in regions without natural elevation. As a PCI and PMI, the project benefits from priority permitting, coordinated cross-border governance, and access to Connecting Europe Facility (CEF) support. It illustrates how the TEN-E fast-track framework can accelerate strategic long-duration storage infrastructure.

Actor Involvement

Actor	Involvement	Role
EU	✓	Enforces TEN-E permitting timelines and PCI procedures
EIB	✓	Provides financing for PCI-eligible infrastructure
Member States	✓	Establish one-stop-shop authorities and implement streamlined permitting
System Operators	✓	Submit and justify PCI and PMI applications
Industries	✗	—
Developers	✓	Prepare and pre-qualify PCI and PMI-ready project designs

4.4.4 Grid Access Reform and Digital Connection Queues

Grid access is one of the most binding constraints for LDES. Long, opaque queues delay projects that would otherwise relieve congestion and integrate renewables. Aligning grid access rules with RED III and TEN-E—through digital queue management, binding deadlines, standardised impact assessments, and transparent publication of available capacity—gives LDES predictable timelines and reduces risk.

STRENGTHS	WEAKNESSES
Can cut connection times from >5 years to under 2 years	—
Frees capacity by filtering “zombie” projects	Needs robust data and IT systems
Directs storage to constrained zones where it adds most value	Implementation depends on NRA and TSO/DSO governance

Case Study: Netherlands – Digital Congestion Management and Real-Time Capacity Maps

In response to severe grid congestion, the Netherlands introduced a national digital congestion-management framework led by TenneT and regional DSOs. From 2022 to 2025, system operators rolled out real-time hosting-capacity maps, transparent queue reporting, and a formal proactive congestion-management regime. Flexible assets, including storage, can now register and be dispatched under non-firm access contracts in constrained zones. This reform has accelerated connection timelines for grid-supportive resources and reduced inactive (“zombie”) queue positions by applying readiness criteria. TenneT reports that the use of digital tools and mandatory transparency requirements has cut assessment times for qualified flexibility projects from several years to under 12 months in multiple congestion areas.

Actor Involvement

Actor	Involvement	Role
EU	✓	Mandates via RED III Article 16
EIB	✓	Finances digital queue platforms
Member States	✓	Align national grid plans
System Operators	✓	Publish real-time heatmaps
Industries	✗	—
Developers	✓	Submit grid-ready designs

4.4.5 Strategic Locational Tenders and Non-Wire Alternatives

Strategic locational tenders procure flexibility in clearly identified grid-constrained areas where system studies show that storage and other flexible resources can defer or optimise network reinforcement. Tenders can be run by TSOs or DSOs and should be open to all technologies able to deliver defined congestion relief, redispatch and local adequacy services, including LDES, shorter-duration storage and demand-side flexibility. To encourage their use, regulators can align incentives by allowing operational expenditure (Opex) solutions to compete with capital expenditure (Capex) when setting regulated returns, as already applied in the United Kingdom.

In qualifying zones (e.g. RES acceleration areas, industrial clusters), these tenders can be combined with streamlined local permitting and transparent congestion-management payments, ensuring deployment matches specific grid needs rather than generic capacity additions.

STRENGTHS	**WEAKNESSES**
Targets locations where flexibility delivers highest system value	Requires robust TSO/DSO coordination and transparent system studies
Can defer or optimise grid reinforcement costs	Limited to areas with clear congestion or reinforcement needs
Eases deployment in pre-identified constrained zones	Must avoid technology bias and ensure fair competition among flexibility options

Case Study: UK Strategic Spatial Energy Plan (SSEP) – 2025 Pilot

National Grid ESO’s SSEP identifies optimal zones for flexibility based on locational value, congestion patterns, and reinforcement costs. The first pilot tender (Q4 2025) is expected to procure 500 MW / 8 GWh of flexibility services in South Wales, where storage is projected to defer approximately £320 million in transmission reinforcement. The pilot demonstrates how spatial planning and locational tenders can align flexibility deployment with network needs.

Actor Involvement

Actor	Involvement	Role
EU	✓	Provides TEN-E and PCI eligibility for major grid-value projects
EIB	✓	Finances flexibility solutions that defer network investment
Member States	✓	Mandate or authorise TSO/DSO locational tenders
System Operators	✓	Publish congestion heatmaps; run tenders; validate system value
Industries	✓	Co-locate flexibility behind the meter in constrained zones
Developers	✓	Bid modular solutions suited to local grid needs

4.5 Summary of LDES-Supporting Options

The instruments presented in this chapter address the specific structural barriers identified earlier. Each tool acts on a different part of the modelling–market–investment–delivery chain, and their effectiveness depends on system needs and technology maturity. No single intervention is sufficient; combined, they create the enabling framework for LDES deployment at scale.

Instrument	Impact on LDES	Ease of Deployment	Explanation
LDES in ERAA/NRAA	High	Low	Improves visibility of multi-day adequacy needs and supports targeted national measures.
Flexibility Needs Assessment	High	Medium	Identifies system-wide flexibility gaps and justifies targeted LDES procurement.
TYNDP Integration / PCI Pathway	Very High	Low	Enables recognition of LDES as a non-wire alternative and access to CEF funding.
Distribution Network Development Plans	Medium	Medium	Creates local procurement pipelines for congestion relief and hosting capacity expansion.
Duration-Aware Capacity Mechanisms	Very High	High	Rewards multi-hour and multi-day availability, providing predictable adequacy revenue.
Ancillary and Stability Markets	Medium	Low	Monetises inertia, voltage support, black-start and multi-hour reserves.
Strategic Locational Tenders	High	High	Procures LDES where it delivers highest locational value and defers grid investment.
Financial Guarantees (EIB/EIF + national)	High	Medium	Reduces lender risk and unlocks higher debt ratios for early commercial LDES.
CapEx Grants under CISAF	High	High	Reduces upfront costs for capital-intensive projects and accelerates deployment.
Tax Credits & Concessional Loans	High	Medium	Lowers net CapEx and cost of capital through ITCs and long-tenor low-interest loans.
Cap-and-Floor Revenue Mechanisms	Very High	Medium	Provides a long-term revenue floor while preserving market exposure.
Energy Storage Taxation Reform	Medium-low	Medium	Removes double charging and aligns taxation rules with storage's system role.
Grid Fee Reform	Medium-low	Medium	Ensures cost-reflective tariffs and supports value-stacking and efficient dispatch.
One-Stop-Shop Permitting & Workforce Upskilling	High	Medium	Reduces permitting delays through coordinated processes and improved technical capacity.
PCI Fast-Track Permitting	High	Medium	Applies binding TEN-E deadlines and priority status to eligible LDES projects.
Priority Grid Access & Digital Queues	High	Medium	Cuts grid-connection delays via transparent, digitalised queue management.

Very High	*High*	*Medium*	*Medium-low*	*Low*
■	■	■	■	■

5. Policy Recommendations

Closing the deployment gap for long-duration energy storage requires a sequenced and coordinated policy framework. LDES cannot be unlocked by a single measure: deployment depends first on identifying system needs, then designing markets that reward flexibility, followed by introducing long-term contracting tools, and finally deploying capital-support instruments to make projects investable. Enabling conditions—permitting, grid access, and institutional capacity—must support each step.

The four priority recommendations below are presented from least to most market-interventionist.

1. ESTABLISH ROBUST LDES MODELLING AND NEEDS ASSESSMENTS

Recommendation:

Mandate explicit assessment of long-duration needs in ERAA/NRAA, Flexibility Needs Assessments, TYNDP/DNDP, and NECPs, expressed in GWh with annual milestones, including advanced storage assets where modelling demonstrates material adequacy, congestion-relief, and stability benefits.

Why:

Clear assessments of multi-hour and multi-day flexibility needs are essential not to justify LDES in abstract terms, but to determine the least-cost mix of resources that can meet reliability standards under realistic renewable, weather, and demand conditions. Without accurate modelling of durations beyond 4 hours, system planning risks over-building generation and grids, relying excessively on fossil back-up. Needs assessments ensure that procurement, market design, and investment decisions are grounded in objective system evidence, not technology assumptions.

To avoid unintended technology bias, LDES policy and planning should not rely on hard duration thresholds. System needs differ across geographies, grid topologies, and load profiles, and least-cost outcomes depend on recognising the system value delivered by storage across a range of durations and operating profiles. Planning and modelling frameworks should therefore assess long-duration storage as a candidate solution across multiple configurations, rather than restricting analysis to a narrow set of predefined durations for modelling convenience, which can subsequently distort real-world procurement outcomes.

Actions:

- Integrate LDES into ERAA/NRAA with appropriate adequacy credit.
- Require national Flexibility Needs Assessments that quantify multi-day needs.
- Include GWh targets in NECPs based on system modelling.
- Treat LDES as a non-wire alternative in TYNDP/DNDP cost-benefit analysis.

2. EXPAND AND REFORM ANCILLARY AND STABILITY MARKETS

Recommendation:

Create or update market products that remunerate LDES for services beyond short-duration balancing, including multi-hour reserves, grid-forming capability, inertia, voltage support, black-start, congestion management, and cost-reflective grid tariffs, provided such frameworks avoid rigid duration thresholds and remain grounded in least-cost, technology-neutral system modelling.

Why:

As conventional synchronous generation declines, system operators require new providers of stability, restoration, and multi-hour balancing. Current ancillary markets were designed for a different generation mix and do not reflect emerging system needs. Updating these products ensures technology-neutral procurement of stability services, improves competition, and reduces reliance on bespoke TSO contracts or derogations. A more complete set of system-services markets also helps avoid passing integration costs to consumers, as the system can secure required services through transparent, market-led processes.

Actions:

- Develop reserve products with availability payments.
- Introduce grid-forming, inertia and voltage support tenders open to LDES.
- Ensure black-start and restoration services include non-thermal options.
- Implement time-of-use grid fees that reward congestion relief and remove double taxation.

3. PROMOTE AND REFORM CAPACITY MARKETS TO FULLY RECOGNISE DURATION

Recommendation:

Adopt duration-aware capacity remuneration where LDES receives full de-rating credit and contract lengths match asset life.

Why:

Capacity mechanisms will increasingly be used across Europe following ACER's ERAA methodology revision and the new fast-track approval path under CISAF. If these mechanisms remain duration-blind, they risk contracting resources that cannot perform during multi-day stress events—creating adequacy gaps and necessitating expensive corrective actions.

Duration-aware design ensures that procured capacity is physically capable of meeting the reliability standards Member States commit to, supports competition between technologies, and allows alignment with harmonised ERAA parameters for streamlined approval.

Actions:

- Introduce de-rating factors based on power and energy (MW+MWh).
- Allow 15–20-year contracts for LDES assets.
- Enable locational capacity procurement in constrained zones.
- Allow project-specific de-rating bids with performance-based penalties.

4. DEPLOY INSTRUMENTS FOR HIGH-CAPEX LDES

Recommendation:

Use targeted public financial tools to reduce WACC and make long-duration projects bankable, building on CISAF and national financing facilities.

Why:

Today, LDES operates predominantly under a merchant model, relying on volatile wholesale-market revenues and limited ancillary service income. This exposure does not provide the long-term cash-flow certainty required to finance high-CAPEX, long-lifetime assets. Capacity markets remain the primary long-term contracting tool in Europe. Unless they explicitly value duration, LDES cannot compete fairly with low-CAPEX thermal assets or short-duration technologies.

Actions:

- Offer capex subsidies for FOAK and early commercial LDES under CISAF.
- Consider cap-and-floor revenue frameworks for LDES.
- Introduce investment tax credits and accelerated depreciation, inspired by the IRA.
- Expand concessional loan facilities via the EIB and national development banks.

Allow blended finance so ITCs, grants, and concessional loans can be stacked coherently.

6. Conclusion

Long-duration energy storage delivers essential system value: firm capacity during multi-hour and multi-day renewable shortfalls, reduced curtailment and import dependence, deeper renewable integration, and stable clean power for industry and data-intensive sectors. These contributions align directly with the priorities set out in President von der Leyen's 2024 Mission Letter, which calls for a strengthened EU initiative on energy storage across all timeframes. Yet deployment remains limited. High upfront capital needs, insufficient long-term revenue visibility, duration-blind market design, and slow or inconsistent permitting and grid-connection processes continue to constrain multi-hour and multi-day technologies—despite consistent evidence from ENTSO-E, the Joint Research Centre (JRC), and national transmission system operators confirming the need for substantial long-duration flexibility.

This paper addresses that gap by identifying deployment barriers, assessing existing and emerging support tools, and proposing a coherent policy pathway aligned with Europe's long-term decarbonisation and adequacy needs.

First, robust modelling and flexibility needs assessments must quantify LDES requirements—volumes, durations, and locations—and translate them into energy-based targets within National Energy and Climate Plans (NECPs), European and National Resource Adequacy Assessments (ERAA/NRAAs), and Ten-Year and Distribution Network Development Plans (TYNDPs/DNDPs). Clear identification of system need underpins all subsequent measures.

Second, ancillary and stability markets must be expanded to provide fair access for LDES alongside other resources, enabling remuneration for services such as multi-hour reserves, black-start capability, grid-forming functions, congestion relief, and cost-reflective grid tariffs.

Third, capacity mechanisms must be reformed to fully credit duration and effective firm energy delivery under stress events. Duration-aware adequacy credit—derived from probabilistic modelling rather than fixed thresholds—combined with long-term contracts, adequate lead times, and, where appropriate, locational procurement, is essential to ensure LDES competes fairly with low-capital-expenditure thermal assets.

Fourth, targeted capital-support instruments remain necessary to lower the cost of capital for high-capital-expenditure, long-lifetime assets. These include capex support, cap-and-floor revenue frameworks, concessional finance, and tax-based incentives, which together enable bankability where market revenues alone remain insufficient.

Delivery ultimately depends on cross-cutting enablers. Fast-track permitting, coordinated one-stop-shop procedures, digitalised grid-connection processes, anticipatory grid planning, and transparent hosting-capacity data are required to ensure LDES can be deployed where system value is highest. These elements build on Energy Storage Europe's complementary work on permitting procedures, grid connections, and energy storage targets for 2030–2050.

Taken together, the measures set out in this paper provide a coherent and implementable pathway. By identifying system needs first, calibrating markets to reward flexibility, enabling long-term contracting, and reducing financing risk, Europe can unlock the long-duration energy storage required for a resilient, decarbonised power system capable of managing variability across hours, days, and seasons. Long-duration energy storage policy should therefore avoid rigid duration thresholds and instead recognise effective firm contribution, controllability, and system stability across multiple time horizons, supported by modelling practices that explicitly assess a range of candidate storage durations to ensure least-cost, technology-neutral outcomes.

7. Annex I: Case Studies

7.1 The CO2 Battery Provides Long-Duration Energy Storage in Italy

Long-duration energy storage is rapidly becoming an essential grid resource: as energy demand from data centres rises, peak demand periods increase in intensity and duration, and higher proportions of renewable energy power the grid, it has never been more important to have a firm, flexible resource making sure that the grid can respond to any stressor optimally and reliably. Energy Dome's CO2 Battery provides one such solution: it is an 8+ hour non-inverter-based resource that can provide a suite of essential grid ancillary services while providing relief from peak demand events. It is a utility-scale asset that can take advantage of energy arbitrage and keep rates low, reliably usher in new large data centre loads, and shift energy toward peak demand.

Figure 2 - Energy Dome Ottana project

Energy Dome utilises two business models to deliver the CO2 Battery to utility and large load customers. The first business model is a Build-Own-Operate model, or "Energy Storage as a Service." In this model, Energy Dome designs, finances, builds, owns, and operates CO2 Battery facilities, delivering energy storage as a service to offtakers. Customers sign a long-term contract (tolling agreement or PPA) for capacity, and the benefits of an 8+ hour storage resource without direct ownership. Energy Dome handles everything from construction to maintenance. The second business model is an Original Equipment Manufacturer (OEM) model, which allows customers to fully own and operate the plant. In this model, Energy Dome provides its patented equipment and plant development expertise to third parties, who purchase and operate the CO2 Battery at their site. This offers full ownership control to the customer and the ability to integrate the system into their asset base.

Energy Dome's first-of-a-kind full-scale 20 MW–200 MWh plant, Project Ottana, is currently operational in Sardinia, Italy. It was delivered under a turnkey Engineering, Procurement, and Construction Management contract to a 100% Energy-Dome SPV. The funding partners for this project are Breakthrough Energy Catalyst, the European Investment Bank, and Energy Dome. The project was constructed at a brownfield site with existing grid interconnection capabilities. This allowed for timely siting, permitting, and interconnection processes. Starting in January 2024, the Energy Dome team completed detail design, development, and construction of the plant – securing transferable learnings on plant development and operation to inform future projects. In July 2025, the project underwent third party engineering testing and validation and met all performance metrics effective August 2025. Today, the project is contracted under a tolling agreement with French utility Engie and being dispatched to the Italian grid. It and is largely being used for energy arbitrage.

7.2 Silver City Energy Storage Centre

As Australia modernises its grid infrastructure and moves towards aggressive carbon emission reductions, it is undergoing one of the most rapid energy transitions in the world. This has brought on significant need for storage to maintain reliability, reduce curtailments and to optimize the renewables that are being added to the grid.

Broken Hill, NSW currently sits at the end of a single radial transmission line that serves the entire Far West region. When it goes down, the only back-up is a set of aging diesel generators, which are also unreliable. Because of the single transmission line, reliability issues are frequent – most recently, in October 2024, the entire region was out of power for more than six days.

This underscored the need for an asset like Hydrostor's advanced compressed air energy storage (A-CAES) to support the grid, which uses compressed air and water to store energy. A-CAES technology is similar to pumped hydro storage, but it uses significantly less land and water, and can be sited more flexibly. A-CAES facilities also provide inertia to the grid and black-start capabilities, which are key to providing reliable power supply with the continued addition of renewables to the grid.

Hydrostor's Silver City Energy Storage Centre (Silver City) can discharge 1,600 megawatt hours (MWh) or 8+ hours of electricity. The project will eliminate the need for billions in investments in expensive new transmission lines, and will serve as a backbone to the region's mini-grid, linking the diverse renewable resources in the area so the region can sustain itself in case of future black-outs. The project will bring in AUD$500M in regional investment, employing hundreds of people during construction, and creating 40 full-time jobs for the facility's 50+ year operational lifetime.

The project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program. In December 2023, Silver City was awarded both a Network Service Agreement with Transgrid, and a Long-Term Energy Service Agreement (LTESA) from AEMO Services under the New South Wales government's electricity infrastructure roadmap highlighting Hydrostor's commercial readiness. Most recently, in February 2025, the NSW government also approved the project's development application. The project is expected to reach financial close in 2026 and anticipated to be operational as early as 2028.

Figure 3 - Hydrostor Silver City Energy Storage

7.3 Ballynahone Energy Storage Centre: Pioneering Multi-Day, Iron-Air Storage in Ireland

As electricity systems integrate higher shares of variable generation and face growing demand from electrification and large industrial loads, the need for long-duration, dispatchable flexibility is becoming increasingly acute. Ireland, as an island system with limited interconnection and an ambition to reach 80% renewable electricity by 2030, is encountering these challenges earlier than many other European systems. In this context, the Ballynahone Energy Storage Centre represents a strategically important demonstration of multi-day long-duration energy storage.

The Ballynahone Energy Storage Pilot Project, developed by FuturEnergy Ireland—a joint venture between Coillte and ESB—will deliver Europe's first utility-scale Iron-Air long-duration energy storage facility. The project is designed with a maximum export capacity of 10 MW and a total storage capacity of 1 GWh, enabling discharge over periods of up to 100 hours. The underlying technology, developed by Form Energy, uses iron, water, and air—materials that are abundant, low-cost, and non-critical—to provide extended-duration storage at a cost profile fundamentally different from conventional generation or short-duration batteries. Commercial operations are planned to commence in 2028. The project is located in County Donegal, within a highly constrained grid area in the northwest of Ireland where renewable generation frequently exceeds local network capacity. This makes Ballynahone a critical test case for how multi-day storage can reduce renewable curtailment, alleviate local congestion, and improve overall system efficiency without immediate reliance on large-scale grid reinforcement. Without such solutions, systems risk increased reliance on fossil generation during supply shortfalls and continued underutilisation of existing renewable assets.

Figure 4 - Ballynahone Energy Storage Centre

Beyond its immediate system benefits, Ballynahone plays a broader strategic role by generating operational data essential for regulators and system operators seeking to integrate long-duration storage into planning, market design, and adequacy assessments. Its deployment also demonstrates the scalability and security advantages of iron-air chemistry, which avoids dependence on constrained global supply chains. FuturEnergy Ireland's internal modelling suggests that similar technologies could unlock several gigawatts of economically viable long-duration storage capacity in Ireland by the mid-2030s, with comparable potential identified in larger European systems. As a pilot project, Ballynahone forms the first step in a wider deployment pathway, providing proof-of-concept for cost reductions through manufacturing scale-up, informing future market and regulatory frameworks, and enabling progression toward larger commercial projects. Its successful operation is expected to support the development of a reliable, low-cost, and resilient power system in Ireland while offering transferable lessons for other European markets facing similar system stresses.

Figure 5 - Tâmega river giga battery

7.4 Tâmega Giga-Battery: A Unique Project Developed in Europe in the Last 25 Years

The Tâmega hydroelectric complex in northern Portugal stands as one of the most significant energy infrastructure projects developed in Europe over the past 25 years and one of the continent's largest energy storage facilities. Developed along the Tâmega River, a tributary of the Douro, the complex comprises three pumped-storage hydropower plants—Gouvães, Daivões, and Alto Tâmega—with a combined installed capacity of 1,158 MW. Together, they represent an increase of approximately 6% in Portugal's total installed electricity capacity as of 2024.

The Tâmega complex is capable of producing around 1,766 GWh of electricity annually and provides a storage capacity of approximately 40 GWh, equivalent to the daily electricity consumption of around 11 million people. This large-scale storage capability allows the system to absorb excess generation during low-demand periods and release energy during peak demand, strengthening system adequacy and reducing reliance on imported fossil fuels. The project is estimated to avoid the import of more than 160,000 tonnes of oil per year and reduce annual CO_2 *emissions by around 1.2 million tonnes.*

With a total investment exceeding €1.5 billion, the project has been supported by significant financing from the European Investment Bank, including a €500 million loan approved in 2018 as part of a broader funding package. Construction and operation of the complex have delivered substantial regional economic benefits, generating thousands of direct and indirect jobs and supporting a wide domestic supply chain. Environmental compensation measures, embedded within the project's Environmental Impact Statement, include large-scale reforestation and biodiversity protection initiatives.

The Tâmega complex is also being developed as a hybrid energy system. Two wind farms with a combined capacity of 274 MW are being added in the surrounding area, enabling coordinated operation between variable generation and pumped storage. This hybrid configuration allows wind generation to supply electricity during peak demand while surplus production is used to power pumping operations during low-demand periods, improving overall system efficiency and market optimisation.

Operationally, the Tâmega giga-battery will provide nearly 900 MW of pumping capacity, increasing Portugal's pumped-storage capability by more than 30%. As one of the most mature and efficient long-duration storage technologies, pumped hydro remains a cornerstone of system reliability, offering high efficiency, long asset lifetimes, and proven performance at scale. The Tâmega project illustrates how large, capital-intensive long-duration storage assets can anchor national decarbonisation strategies, support system flexibility, and safeguard security of supply in power systems with growing shares of variable generation.

8. Annex II: International and Multilateral Initiatives Relevant to LDES

This annex provides a non-exhaustive overview of international and multilateral initiatives that are relevant to long-duration energy storage but are not analysed in detail through this paper.

- **Paris Pledge on Long-Duration Energy Storage**

Launched in September 2025 by the International Hydropower Association (IHA) and Eurelectric, this is a collective commitment from over 50 utilities, hydropower suppliers, and energy associations (including Energy Storage Europe) to ease the deployment of pumped storage hydropower (PSH) as a proven LDES technology. It calls for urgent EU and national regulatory support to unlock a ~35 GW pipeline of PSH projects in Europe, emphasizing distinct treatment of long-duration storage in legislation, streamlined permitting, and fair remuneration for system services.

- **Global Energy Storage and Grids Pledge**

Initially proposed at COP28 (2023) with targets for 1,500 GW of energy storage and 25 million km of grids by 2030, this pledge was formally launched and expanded at COP29 (2024) to support tripling renewables. As of late 2025, it has garnered support from over 58 countries and numerous organizations, with utilities committing to increased investments (e.g., USD 148 billion annually via the Utilities for Net Zero Alliance). It explicitly recognises LDES for system resilience.

- **Mission Innovation**

A government-led collaboration under Mission Innovation focused on accelerating innovation, demonstration, and cost reduction of long-duration energy storage technologies. The mission promotes coordinated RD&D, pilot projects, and international knowledge sharing to enable commercial deployment.

- **World Bank / Energy Sector Management Assistance Program (ESMAP)**

Through ESMAP, the World Bank supports analytical work and pilot projects on grid-scale storage, including long-duration solutions, particularly in emerging and developing economies. The focus is on system reliability, integration of renewables, and investment frameworks.

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About the Energy Storage Europe Association:

The Energy Storage Europe Association is the leading member-supported association representing organisations active across the entire energy storage value chain. The Association supports the deployment of energy storage to further the cost-effective transition to a resilient, carbon-neutral, and secure energy system. Together, Energy Storage Europe Association members have significant expertise across all major storage technologies and applications. This allows us to generate new ideas and policy recommendations that are essential to build a regulatory framework that is supportive of storage.

For more information, please visit www.energystorageeurope.eu

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Disclaimer:

This content was elaborated by the Energy Storage Europe Association and reflects a consolidated view of its members from an energy storage point of view. Individual Energy Storage Europe Association members may adopt different positions on certain topics from their corporate standpoint.

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