AURORA ENERGY RESEARCH

Breakthrough Energy

Long Duration Energy Storage in Spain

Energy Storage Coalition – High-Level Round-Table

October 2023

LDES is a cost-efficient way to reduce reliance on gas while avoiding renewable curtailment, but there are still challenges for its deployment

AURORA

The 2023 NECP proposes a 173% increase (or 85 GW) in renewable capacity by 2030 from current capacities[1]; storage[2] is expected to increase by 487%, or 15 GW from installed capacity. Long Duration Energy Storage (LDES) can ensure renewable energy is utilised in the system while decreasing reliance on CO_2 emitting technologies

Key results of modelling the use of Long Duration Energy Storage (LDES) in the Spanish power system

1	Lower power system costs	A power system with 15 GW of Long Duration Energy Storage (LDES) by 2050 accumulates a total system **cost advantage of around 1 Bn €** (2025-2060) compared to a scenario without LDES
2	Higher utilisation of renewable energy	LDES absorb renewable electricity by charging in hours in which renewables (RES) production exceeds demand; **economic curtailment is eliminated by 2035**
3	Lower natural gas use	LDES replaces thermal generation and ensures security of supply; Net Zero in the power sector is **achieved 5 years earlier**
4	Decarbonising industry	By 2025, some thermal storage assets are already competitive with existing technologies like gas boilers, **avoiding CO_2 emissions in the industrial sector**
5	Increasing profitability of LDES technologies	The **need for storage in Spain is recognised by policymakers**, targeting 18 GW of storage[2] by 2030 and allocating subsidies under PERTE ERHA; however, the calls' design is not suitable for LDES
		LDES cannot rely on near-term price signals for investment; **contracted revenue confidence** and **addressing missing markets for system and grid services'** not procured individually are necessary

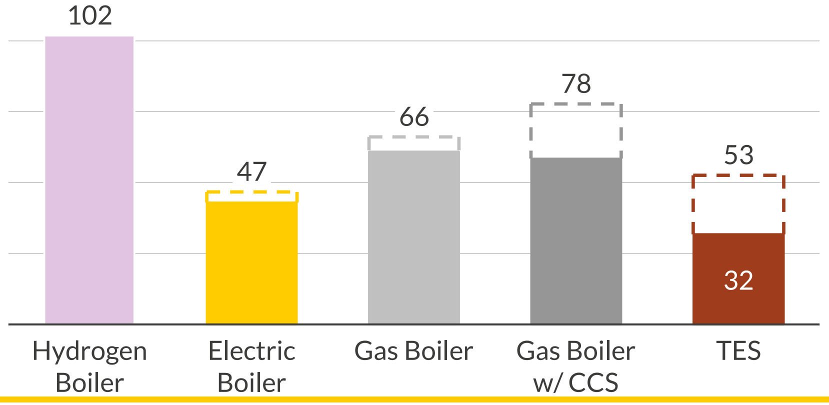
1) Solar PV and onshore and offshore wind combined. 2) Draft 2023 NECP "daily, weekly, seasonal" storage. Peninsular target. Does not include solar thermal. National target including solar thermal sums up to 22 GW.

High upfront costs, combined with a lack of revenue certainty and market signals, would lead to underinvestment; policy support for LDES is required

AURORA

Power-to-heat

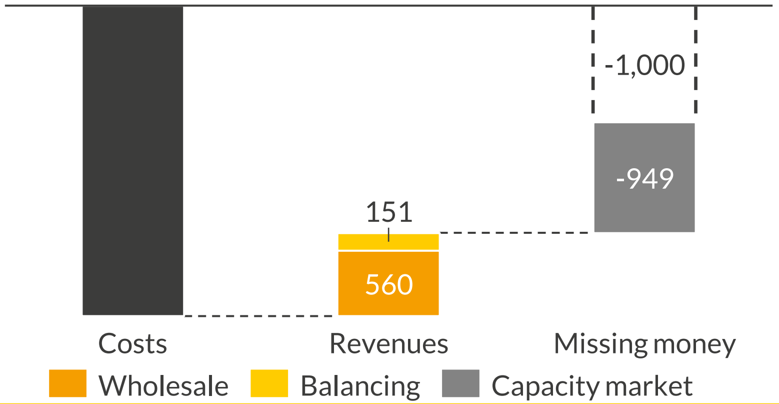
Levelised cost of heat (LCOH) for COD 2025[1]
€/MWh (real 2021)



- **Thermal storage can be competitive by 2025:** By 2025, there are thermal energy storage (TES) assets already competitive with existing technologies by only charging in the hours of lowest price each day (reducing variable costs), resulting in LCOH of ~32 €/MWh
- **High capital costs:** Despite TES effectively benefiting from market volatility, investment costs[2] are still higher than that of an electric boiler; thus, some TES configurations require a subsidy to compete
- **Current retail charges framework worsens the business case:** co-location of TES was assessed as a route to minimise variable costs and retail charges. In a scenario with capture prices below LCOE, benefits of signing PPAs by 2025 are only seen if TES pay retail charges (current design penalises consumption in the middle of the day)

Power-to-power

12h storage deep dive[3]: present value of cashflows for COD 2025, €/kW (real 2021)



- **LDES cannot rely on near-term price signals:** By 2025, considering existing revenue streams in Spain (wholesale and balancing markets) in the LDES scenario, there is a funding gap dependent on the configuration[4]
- **Contracted long-term revenue can help bridge the gap:** To achieve a 7% IRR, all assets would require a subsidy ensuring between 73% and 88% of its investment costs[2] . Other revenue streams like the proposed Spanish capacity market would not be enough to bridge the missing money gap
- **Address missing markets:** Since LDES is suitable to fulfil the system's requirements, missing money could be recovered via the provision of auxiliary services; however, these services are not procured individually
- **Cost declines expected to improve business case:** Costs are anticipated to fall over time, improving the business case by 2030; however, cost decline rates will depend on level of deployment and learning rate

1) Range of configurations tested (min in full, max in dashed). 2) Investment costs include capital and operational expenditure. 3) Business case and results shown here for a 12h asset with certain technical parameters and costs. Results differ for each asset modelled. 4) Different technical parameters and costs.

While Spain has storage capacity target of 20 GW by 2030, specific regulatory policies targeting deployment of long-duration storage are needed

AURORA

Regulatory aspect	What has been done in Spain	Policy considerations and lessons learnt from other countries
Taxes and levies	▪ Circular 3/2020 exempts some types of storage from grid charges if energy is reinjected back into the grid	▪ Thermal energy storage (TES) operating as power-to-heat would not reinject energy back to grid and would have to pay grid charges, increasing LCOH (A) ▪ Possible measures could be a **tariff structure revision or exemption for thermal storage**
Provision of other non-frequency services	▪ CNMC has approved the conditions for non-frequency and other ancillary services for the operation of the Spanish system	▪ **A significant proportion of LDES value would come from the provision of other grid auxiliary services** currently provided by synchronous generators ▪ However, current **Operating Procedures still need to be adapted for the conditions to apply**
Access to electricity markets	▪ Energy storage assets can participate in day-ahead and balancing markets ▪ The proposal for the introduction of a capacity market (CM) foresees the participation of storage; however, **current proposal only foresees 5-year contracts and de-rating factors have not been defined yet**	▪ The introduction of capacity markets is beneficial for storage since capacity contracts offer a predictable income stream and it would improve the business case ▪ In Italy and the UK latest auctions storage got awarded 29% and 60% of the contracts respectively; however, CM has not proven enough to incentivise LDES in other geographies
Storage direct subsidies	▪ The government allocated funds to support the development of storage with a COD until 2026 under PERTE-ERHA[1] ▪ Nevertheless, subsidies' design so far for hybrid and standalone calls either **do not target LDES or include conditions detrimental to LDES technologies** (B)	▪ Italy recently published an auction scheme for the procurement of storage capacity. It is a capacity-based remuneration for the entire investment horizon in exchange for the obligation to make the capacity available to market operators through a centralised platform ▪ In GB, £6m of funding have been awarded to new LDES technologies through tenders. A BEIS[2] consultation in 2021 gathered responses on grid support, barriers and possible mechanisms (e.g., cap & floor) to support investment

(X) *Deep dive*

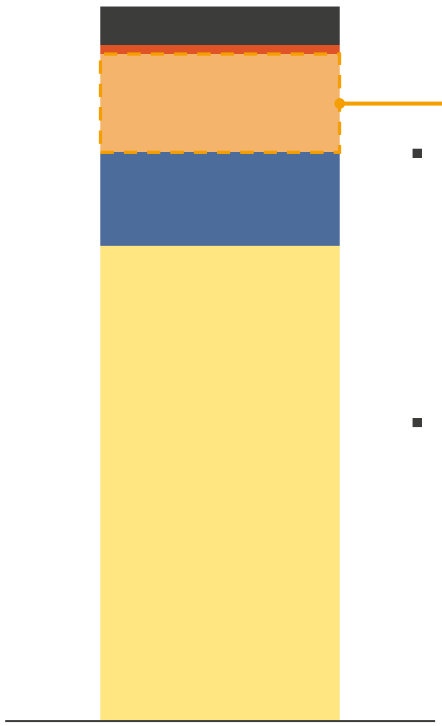
1) Proyecto Estratégico para la Recuperación y Transformación Económica (PERTE) de Energías Renovables, H_2 Renovable y Almacenamiento (ERHA). 2) UK's Department for Business, Energy & Industrial Strategy (BEIS).

Current tariffs penalise energy consumption during the middle of the day, when solar output is at its peak

AURORA

Power-to-heat

Electricity cost components for industrial consumers[1], €/MWh



- In our analysis for thermal storage, we consider the retail charges that apply to an industrial consumer under tariff 6.2. TD (32-72.5 kV)
- Retail charges include all regulated costs: network tolls, capacity payments and charges related with promotion of renewables (inc. tariff deficit)

Energy component of the retail charges (regulated costs)
€/MWh

Hour in the day

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	20.4	26.9	26.9	26.9	26.9	26.9	20.4	20.4	20.4	20.4	26.9	26.9	26.9	26.9	20.4	20.4
2	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	20.4	26.9	26.9	26.9	26.9	26.9	20.4	20.4	20.4	20.4	26.9	26.9	26.9	26.9	20.4	20.4
3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	11.4	20.4	20.4	20.4	20.4	20.4	11.4	11.4	11.4	11.4	20.4	20.4	20.4	20.4	11.4	11.4
4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.4	6.5	6.5	6.5	6.5	6.5	2.4	2.4	2.4	2.4	6.5	6.5	6.5	6.5	2.4	2.4
5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.4	6.5	6.5	6.5	6.5	6.5	2.4	2.4	2.4	2.4	6.5	6.5	6.5	6.5	2.4	2.4
6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	6.5	11.4	11.4	11.4	11.4	11.4	6.5	6.5	6.5	6.5	11.4	11.4	11.4	11.4	6.5	6.5
7	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	20.4	26.9	26.9	26.9	26.9	26.9	20.4	20.4	20.4	20.4	26.9	26.9	26.9	26.9	20.4	20.4
8	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	6.5	11.4	11.4	11.4	11.4	11.4	6.5	6.5	6.5	6.5	11.4	11.4	11.4	11.4	6.5	6.5
9	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	6.5	11.4	11.4	11.4	11.4	11.4	6.5	6.5	6.5	6.5	11.4	11.4	11.4	11.4	6.5	6.5
10	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.4	6.5	6.5	6.5	6.5	6.5	2.4	2.4	2.4	2.4	6.5	6.5	6.5	6.5	2.4	2.4
11	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	11.4	20.4	20.4	20.4	20.4	20.4	11.4	11.4	11.4	11.4	20.4	20.4	20.4	20.4	11.4	11.4
12	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	20.4	26.9	26.9	26.9	26.9	26.9	20.4	20.4	20.4	20.4	26.9	26.9	26.9	26.9	20.4	20.4

Capacity component of the retail charges (regulated costs)
€/kW/year

Hour in the day

Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	18.1	20.9	20.9	20.9	20.9	20.9	18.1	18.1	18.1	18.1	20.9	20.9	20.9	20.9	18.1	18.1
2	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	18.1	20.9	20.9	20.9	20.9	20.9	18.1	18.1	18.1	18.1	20.9	20.9	20.9	20.9	18.1	18.1
3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	9.5	18.1	18.1	18.1	18.1	18.1	9.5	9.5	9.5	9.5	18.1	18.1	18.1	18.1	9.5	9.5
4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.5	8.7	8.7	8.7	8.7	8.7	2.5	2.5	2.5	2.5	8.7	8.7	8.7	8.7	2.5	2.5
5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.5	8.7	8.7	8.7	8.7	8.7	2.5	2.5	2.5	2.5	8.7	8.7	8.7	8.7	2.5	2.5
6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	8.7	9.5	9.5	9.5	9.5	9.5	8.7	8.7	8.7	8.7	9.5	9.5	9.5	9.5	8.7	8.7
7	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	18.1	20.9	20.9	20.9	20.9	20.9	18.1	18.1	18.1	18.1	20.9	20.9	20.9	20.9	18.1	18.1
8	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	8.7	9.5	9.5	9.5	9.5	9.5	8.7	8.7	8.7	8.7	9.5	9.5	9.5	9.5	8.7	8.7
9	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	8.7	9.5	9.5	9.5	9.5	9.5	8.7	8.7	8.7	8.7	9.5	9.5	9.5	9.5	8.7	8.7
10	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	2.5	8.7	8.7	8.7	8.7	8.7	2.5	2.5	2.5	2.5	8.7	8.7	8.7	8.7	2.5	2.5
11	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	9.5	18.1	18.1	18.1	18.1	18.1	9.5	9.5	9.5	9.5	18.1	18.1	18.1	18.1	9.5	9.5
12	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	18.1	20.9	20.9	20.9	20.9	20.9	18.1	18.1	18.1	18.1	20.9	20.9	20.9	20.9	18.1	18.1

1) Illustrative example of the breakdown of the electricity cost for an industrial consumer under the retail tariff set by Circular 3/2020.

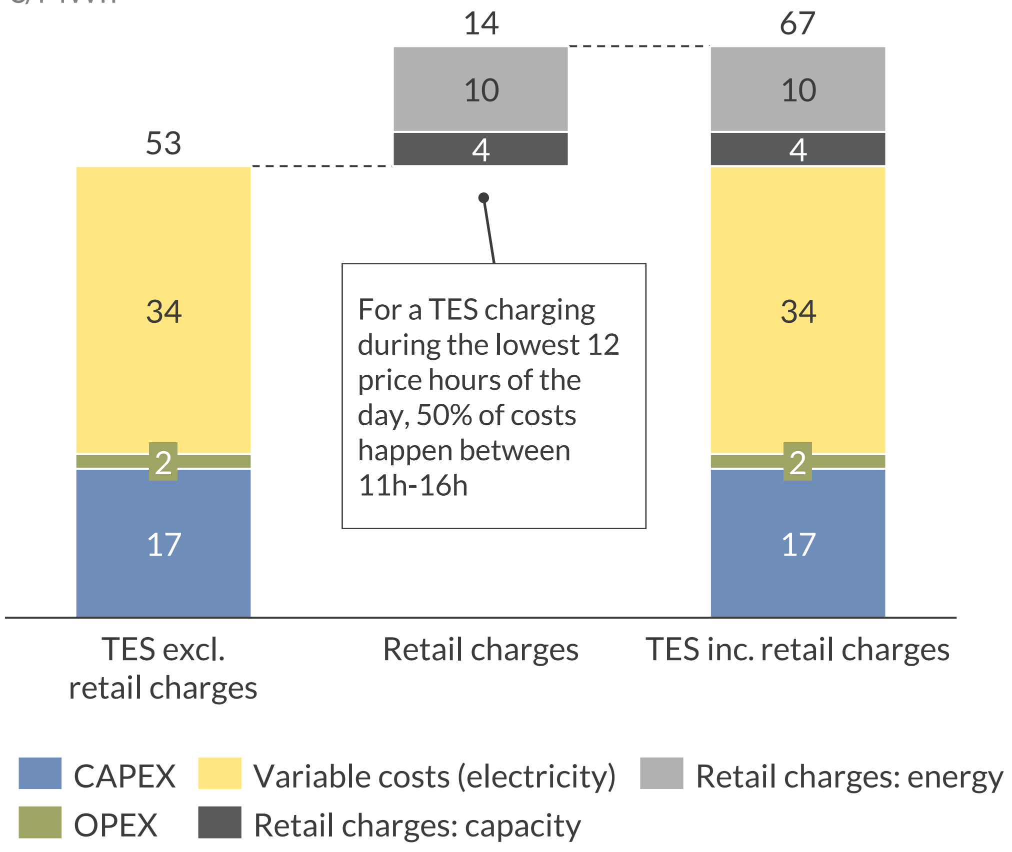
Source: Aurora Energy Research, Circular 3/2020

Unless there are regulatory changes, current tariffs penalise TES energy consumption during the middle of the day, worsening the business case

Power-to-heat

In our analysis, we have not accounted for grid charges. Even though Circular 3/2020 exempts storage from grid charges, this only applies if energy is reinjected into the grid. For TES operating as power-to-heat, energy would not be reinjected back; thus, within the regulatory framework, TES would have to pay grid charges[1]

Levelised cost of heat (LCOH) for COD 2025
€/MWh



- Considering an industrial consumer connected at medium-high voltage, if grid charges were applied to the thermal storage asset, the levelised cost of heat would increase by 28% compared to our base case, or by 14 €/MWh
- Grid charges are divided into two components which vary depending on the time at which energy is consumed, and the maximum capacity contracted in each period
- The current tariff structure penalises capacity and energy consumption in the middle of the day
- TES charges during the hours of the day with the lowest prices, which are usually in the middle of the day driven by high levels of solar generation
- For a TES charging during the 12 hours of the day with the lowest price, 50% of the retail charges happen between 11h-16h

Policy recommendation

- Possible measures to incentivise the TES business case could be:
  - Revise tariff structure to reflect lower costs when there is high solar output
  - Exempt TES from grid charges given that is outputting heat (in some cases, TES discharges power and heat), if avoiding CO_2 emissions in the industry sector

1) Retail charges would also apply to electric boilers. For the electric boilers case, providing same thermal output as this TES, LCOH would be increased by 9.5 €/MWh. Namely, from 43 €/MWh (lower case) to 52.5 €/MWh and from 47 €/MWh (high case) to 56.5 €/MWh. This is comparable with the 67 €/MWh LCOH for the TES with retail charges.

Storage is eligible for subsidies under PERTE ERHA in Spain, but the design of the calls is not suitable for emerging technologies

AURORA

- **In Spain, subsidies for storage will be granted through four calls under the PERTE ERHA[1] scheme. The PERTE ERHA includes storage, renewables and hydrogen and it is funded by the European Union**
- **In October 2023, funding for PERTE ERHA and PERTE industrial decarbonisation have been increased from 6.6 bn€ to 10.8 bn€ and from 450 mn€ to 3.2 bn€, respectively**

1 PERTE-ERHA calls support storage and thermal projects and could represent an opportunity for LDES

PERTE ERHA call	Status
Innovative R&D storage projects	Final resolution published in Feb 2023
Innovative co-located energy projects with electricity generation from renewable sources	Applications opened from Jan to Mar 2023
Innovative stand-alone storage and thermal storage	Applications opened from Sep to Oct 2023

- Calls aim to be technologically neutral, available for all technologies
- Subsidies are allocated based on a point-based system, based on different criteria (i) economic feasibility, ii) enabling renewable penetration, iii) project feasibility and iv) social and environmental impact of the project)
- One of the key barriers for LDES are high upfront costs, but a near-term investment in LDES can reduce costs and long-term risk to security of the system's decarbonisation

2 However, the design of the calls is not suitable for emerging long-duration competing with more mature short-duration technologies

- Similar to previous calls, one of the requirements in the last call is that projects must be built by mid 2026
- Although first calls had a limit of 15 mn € per project, last call included new limits:
  - **50 mn €** per project for stand-alone power storage assets
  - **6 mn €** per project for thermal assets
- No specific TRL (Technology Readiness Level) is required
- For stand-alone power storage assets:
  - Even though there is distinction between durations, projects with **longer duration than 8h** are all awarded the same score
  - Projects with efficiencies **below 65%** (inc. losses from all elements associated with storage system) score 0 in efficiency criteria
  - Providing **grid services** such as inertia, short circuit levels or voltage control is also positively considered. These assets achieve better scores, thus a higher position in the ranking, increasing the probability of getting the subsidy

1) Proyecto Estratégico para la Recuperación y Transformación Económica (PERTE) de Energías Renovables, H_2 Renovable y Almacenamiento (ERHA).

Sources: Sede electronica IDEA, Addendum PERTE Oct 2023

AURORA

ENERGY RESEARCH