IMPERIAL

Integration of LDES in energy and capacity markets: missing money and system adequacy

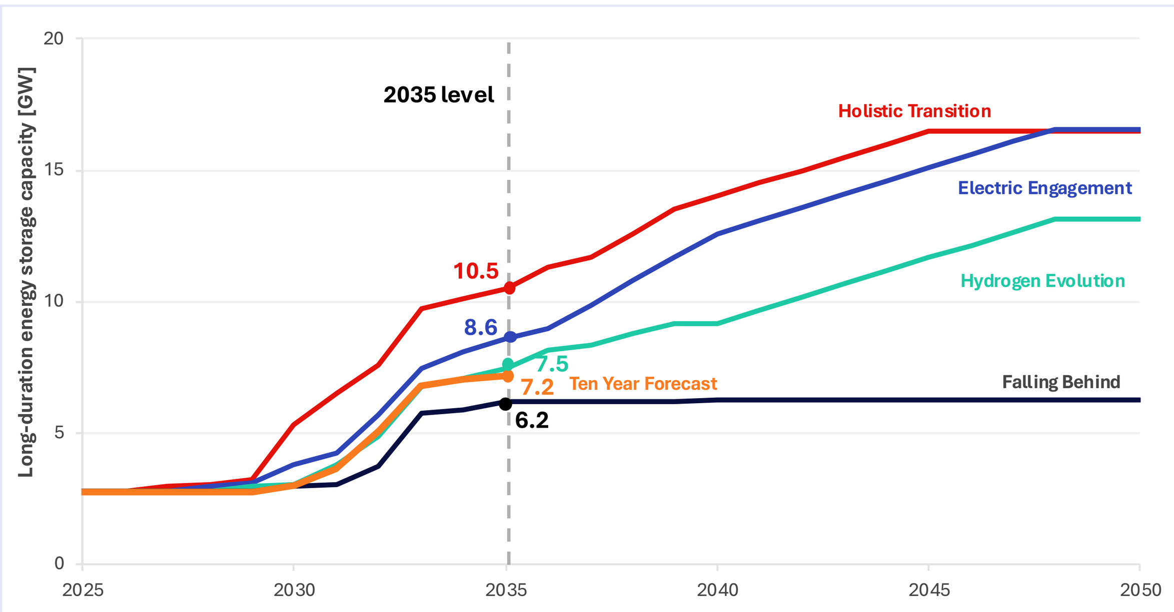
Adam Suski[1]
Elina Spyrou[1]
Richard Green[2]

[1] Department of Electrical and Electronic Engineering, Imperial College London
[2] Imperial College Business School, Imperial College London
Contact: Adam Suski, a.suski23@imperial.ac.uk

Background and motivation

Decarbonizing power systems require a rapid scale-up of energy storage capacity, especially where clean, firm alternatives are limited.

Modelling studies show that the expansion of energy capacity outpaces that of power capacity, highlighting the **critical role of long-duration energy storage (LDES)** in enabling deep decarbonization.



Long-duration energy storage installed capacity (excluding electric vehicles and hydrogen) in UK's Future Energy Scenarios 2025 (adapted from [1]). LDES in FES includes primarily pumped hydro and liquid air energy storage. Hydrogen is treated as a separate category, but its modelled duration reaches 120 hours.

Challenge

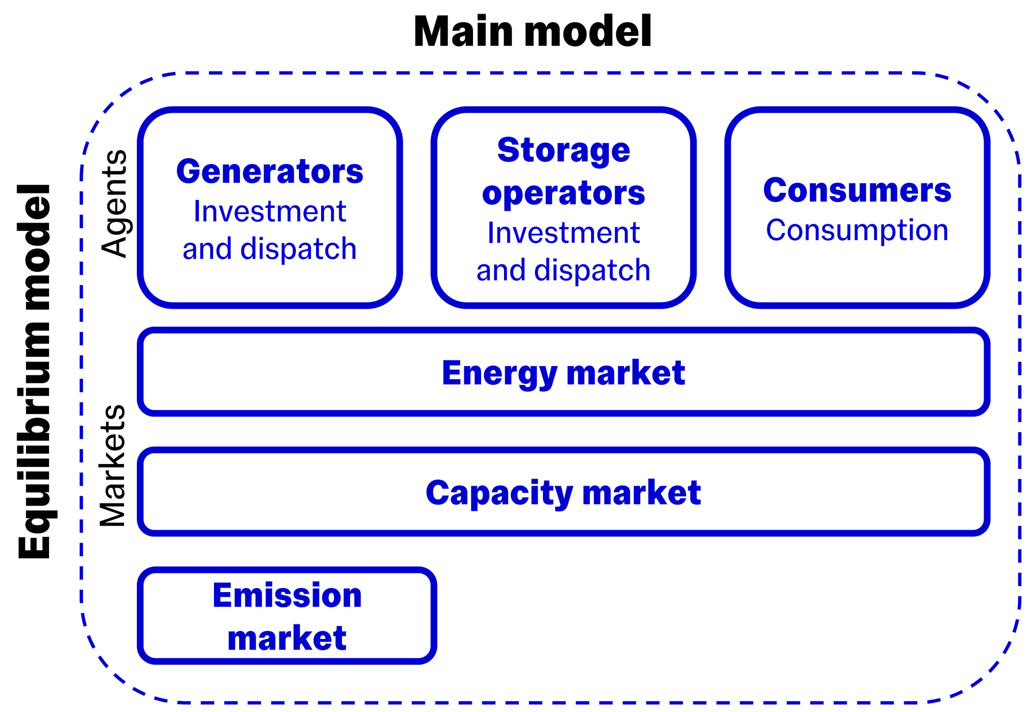
Incompatible business models: Market designs and revenue structures may fail to support LDES, increasing reliance on capacity payments and raising "missing money" risks.

Main research question

To what extent can well-calibrated capacity markets, incorporating marginal accreditation, support efficient investment outcomes in systems with high LDES participation?

Methodology

- Two-stage stochastic capacity investment equilibrium model (investment + dispatch)
- Solved for various combinations of market designs
- Resource accreditation uses the marginal equivalent firm capacity (EFC) method.

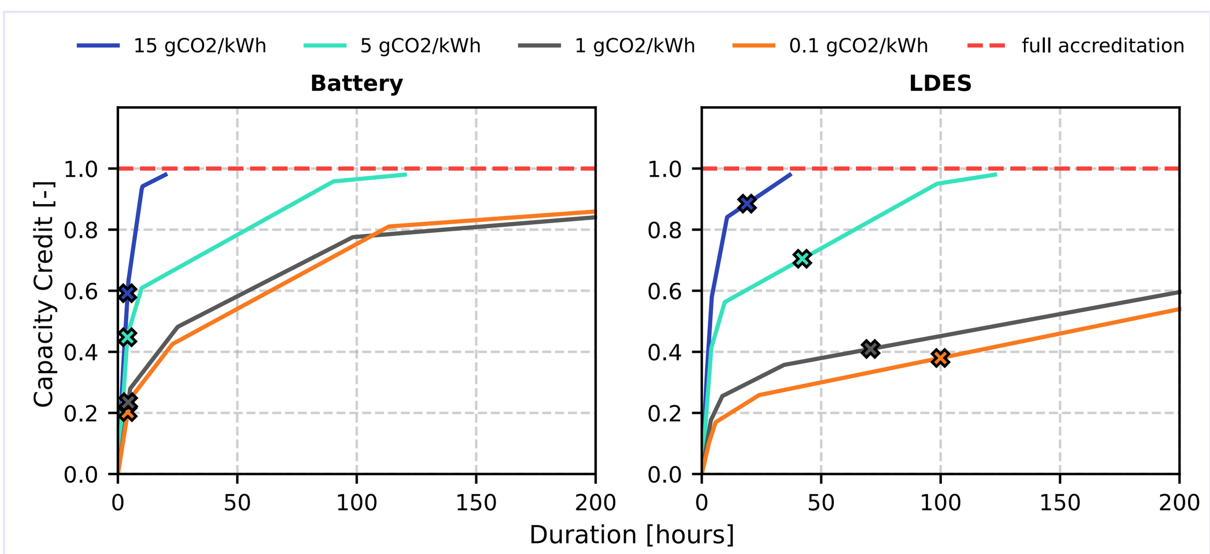


Case study

- *System*: Single node, Greenfield expansion; Based on GB market; *Technologies*: Solar PV, Onshore Wind, Battery Storage, LDES, CCGT w/ CCS; *Emissions* limits: 15 to 0.1 gCO_2/kWh.

Result 1: Storage accreditation

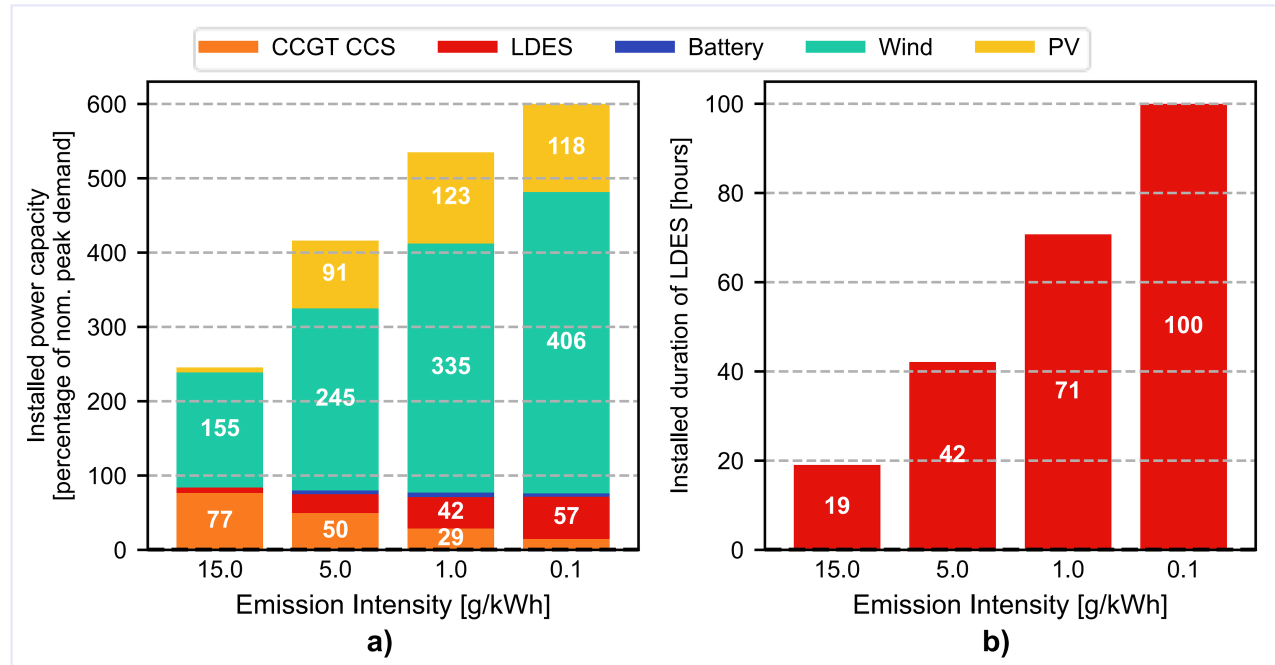
Storage capacity credits decline sharply as the system decarbonizes. Lower roundtrip efficiency further reduces credits for LDES.



Marginal capacity credit estimates as a function of storage duration. Markers indicate credit obtained with duration from EOM VOLL.

Result 2: The need for LDES

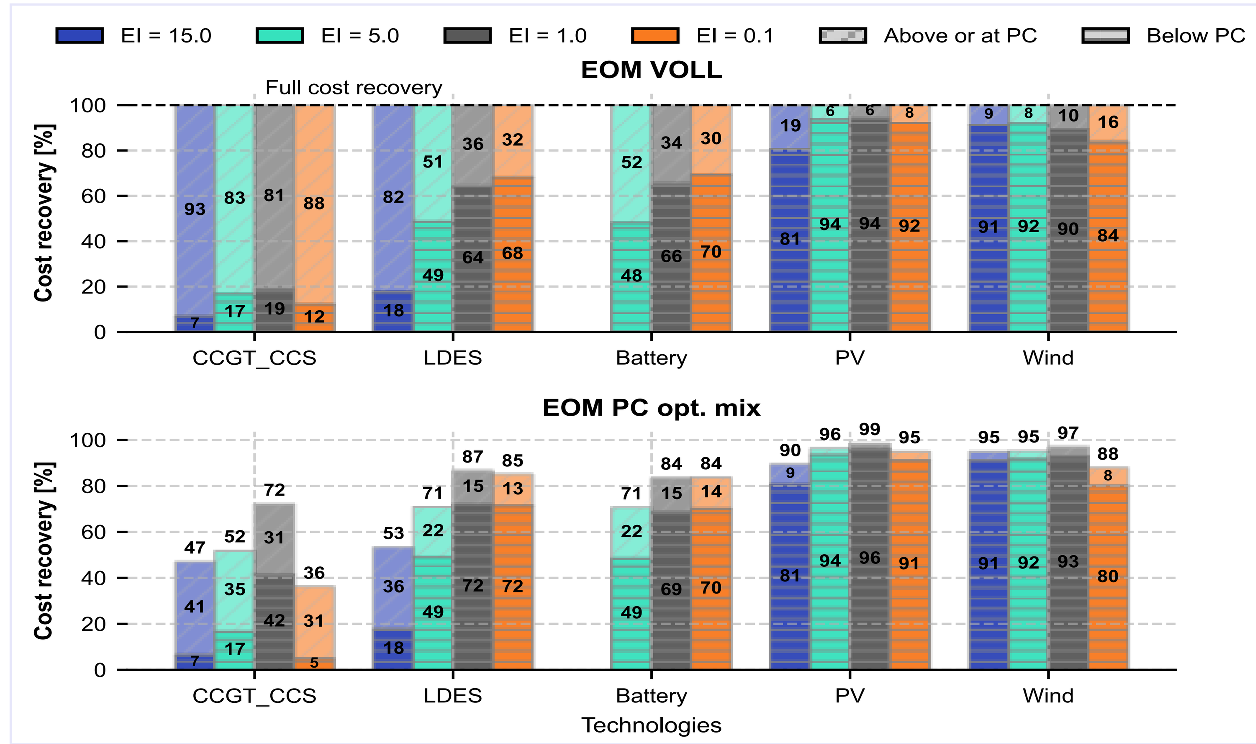
For stricter emission limits, the VRE capacity grows and diversifies, while LDES increasingly substitutes CCGT-CCS. Installed LDES energy capacity rises faster than power capacity, boosting duration.



Capacity results for the 'EOM with VOLL' simulations. a) shows the installed power capacity as a percentage of peak demand, while b) shows the installed duration of LDES.

Result 3: The missing money for LDES

are substantial, but they decline with deeper decarbonization. Due to intertemporal constraints on storage, price cap impacts extend beyond scarcity hours.



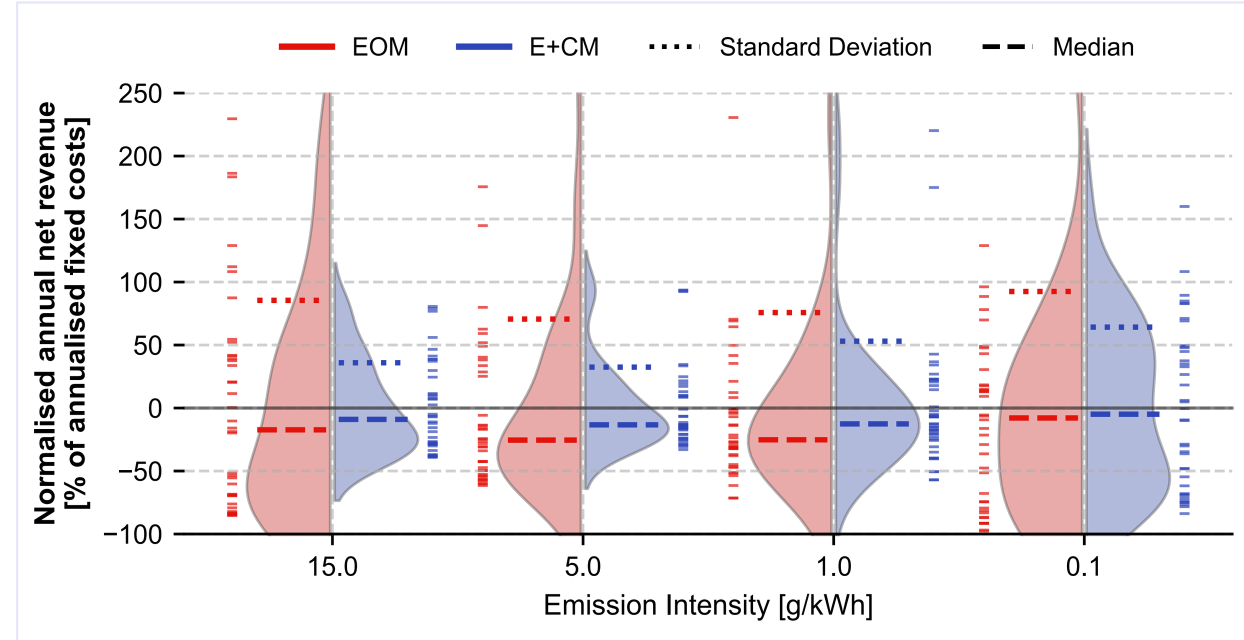
Cost recovery of all technologies in VOLL EOM and VOLL EOM opt. mix. cases.

Result 4: A well-calibrated CM is effective

With moderate storage shares, CM recovers the optimal mix. At higher shares, mis-accreditation and price caps impact storage dispatch, introducing noticeable inefficiencies.

Result 5: LDES revenue volatility varies

For less strict emission limits, the CM effectively reduces revenue volatility and downside risk—though this stabilizing effect diminishes as constraints tighten.



Distribution of annual net revenues for LDES across emission intensity cases

Discussions and further work

Our results show that in the short to medium term, capacity markets with marginal accreditation can yield efficient outcomes. However, as decarbonisation deepens, accreditation becomes more complex, variable, and prone to error. Both accreditation methodologies and definitions of missing money should be revisited as LDES plays a bigger role.

Ongoing work focuses on the role of market incompleteness and risk aversion (with Jacob Mays at Cornell University).

Future work should recognize intra-annual variability on VRE and load levels and examine the interactions of investment incentives with incentives for effective storage dispatch.

Acknowledgments

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[1] National Energy System Operator, Future Energy Scenarios 2025