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THE EFFECT OF DEPLOYING LARGE-SCALE ENERGY STORAGES IN ITALY

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Abstract

Decarbonising the energy system requires deploying a significant amount of large-scale energy storage (LES) devices to deal with the intermittency of renewable energy sources, such as wind and solar. In this work, we analyse the system-level impact of deploying LES in Italy, focusing on social welfare and carbon abatement. The results show that the costs of LES need to decrease to justify their widespread adoption at the transmission level. However, deploying LES today could significantly help reduce carbon emissions, particularly in regions with fewer interconnections, such as Sardinia.

Keywords: energy storage; electricity market; carbon emission

1. Introduction

Large-scale energy storage (LES) systems are essential to achieve net-zero emissions by 2050 and decarbonise the energy system (IEA, 2022). Globally, it is estimated that investments in LES need to scale significantly, reaching 1.5–2.5 TW and 85–140 TWh by 2040, with an estimated cost of up to $3 trillion (McKinsey, 2021). Pumped hydro energy storage has long supported power grids during peak times, but this is no longer sufficient, and orders of magnitude more than current energy storage capability are required to meet net-zero carbon scenarios and to deal with the intermittency of renewable energy sources (EntsoE, 2023).

In this context, a key aspect to consider is the location where energy storages are deployed, as this can substantially impact the actual carbon emission reduction and social welfare. This is particularly relevant in constrained networks, where energy storages may actually contribute to shifting the generation mix towards dirtier sources, increasing carbon emissions (Bardwell et al., 2023).

This work aims at assessing the system-level effect on carbon emissions and social welfare of deploying large-scale energy storages in different areas of Italy, with a focus on lithium-ion batteries, while accounting for both operation and investment costs. A high-fidelity network model of the Italian electricity system consisting of more than 2,000 electrical elements (including AC transmission lines, transformers, and HVDC cables) is developed. We use this network, and actual wholesale market data (GME, 2023) to simulate the Italian day-ahead electricity market clearing process and assess how deploying large-scale energy storages in different locations in Italy can affect social welfare and carbon emissions.

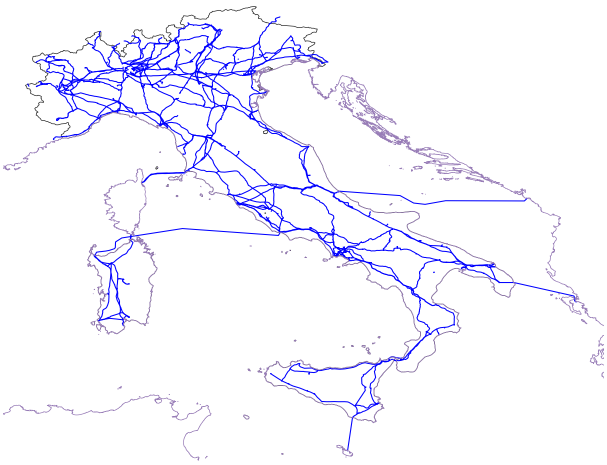

Figure 1 Italian high-voltage (≥220kV) transmission network.

2. Methods

The high-fidelity Italian transmission network has been created by using the data of the European high-voltage transmission grid obtained from EntsoE (EntsoE, 2022), which includes the existing Italian grid (sketched in Figure 1), as well as the planned expansions up to 2025. To assess the change in social welfare due to the deployment of energy storages, we simulated the Italian day-ahead market clearing using the actual market data obtained from the Italian market operator (GME, 2023). The data refers to the first week of February 2023, and each day includes approximately 71,000 market orders, on average. To assess the impact on social welfare of deploying LES, we have explicitly considered the costs of investing and operating lithium-ion (Lithium-iron-phosphate, LFP) batteries, which have been obtained from Viswanathan et al., (2022). These costs are reported in Table 1 together with additional parameters, including depth-of-discharge (DoD), round-trip efficiency, and decommissioning costs. Fixed operation and management costs include replacement expenditures to account for degradation. By using these parameters, we computed an equivalent discounted cost of 94 Euro per hour, which can be regarded as the equivalent hourly constant cost of building and operating the lithium-ion battery throughout the project's lifetime.

Parameters	Energy storage parameters
Rated Power (MW)	10
Duration (h)	2
Capex – Energy ($/kWh)	461.15
Fixed O&M ($/kW-year)	2.79
Decommiss. Costs ($/kWh)	2.65
Round-trip Eff.	83%
Project life (years)	20
DoD	80%
Disc. factor - WACC	7%

Table 1 Cost parameters for the lithium-ion battery used in the test cases.

3. Results

To assess the system-level effect on social welfare and carbon emission of deploying large-scale energy storages, we compare a base case with no storage, with several test cases. Each test case is obtained by deploying the lithium-ion battery described in the previous section in a specific region of Italy. For each region, the battery is assumed to be physically connected to the node of the electrical grid with the highest demand, as reported in EntsoE (2022). Table 2 shows the obtained results. The region where deploying the grid-scale lithium-ion battery is the most beneficial, from a system-level perspective, is the island of Sardinia (see the second column in Table 2).

Region	Potential benefit (€/h) (A)	Storage investment and O&M cost (€/h) (B)	Net benefit (€/h) (C=A-B)
Sardinia	186	94	92
Trentino Alto Adige	38	94	-56
Friuli Venezia Giulia	36	94	-58
Veneto	36	94	-58
Campania	36	94	-58
Sicily	36	94	-58
Calabria	36	94	-58
Basilicata	36	94	-58
Marche	36	94	-58
Apulia	36	94	-58
Abruzzo	36	94	-58
Molise	35	94	-58
Umbria	35	94	-59
Lazio	35	94	-59
Tuscany	35	94	-59
Emilia Romagna	35	94	-59
Lombardy	35	94	-59
Liguria	35	94	-59
Piedmont	35	94	-59
Aosta Valley	35	94	-59

Table 2 The table shows the effect on social welfare of deploying a lithium-ion LFP battery (10 MW, duration of 2 hours) in different regions of Italy.

However, if we consider investment and management costs, the net benefit (fourth column) for all regions, except Sardinia, is negative. This means that despite the potential benefit, the current costs of lithium-ion batteries need to decrease to justify their widespread adoption at the grid scale. However, periods with higher demand and/or more intermittent renewable resources (particularly solar power) might yield higher potential benefits. Note furthermore that a capacity market has been recently introduced in Italy (Terna, 2022), implementing a reliability option scheme (Cramton et al., 2013), which has awarded a payment of up to 51 k€/year per MW of derated[1] capacity in the latest auction. These payments contribute to the revenues of storage investors and are recovered through tariffs levied on electricity users. These monetary flows have not been considered in this work as they cancel each other at the aggregate level.

However, deploying large-scale lithium-ion batteries could be significantly beneficial in terms of carbon abatement, as shown in Figure 2. This figure highlights the potential carbon emission reduction achievable by deploying

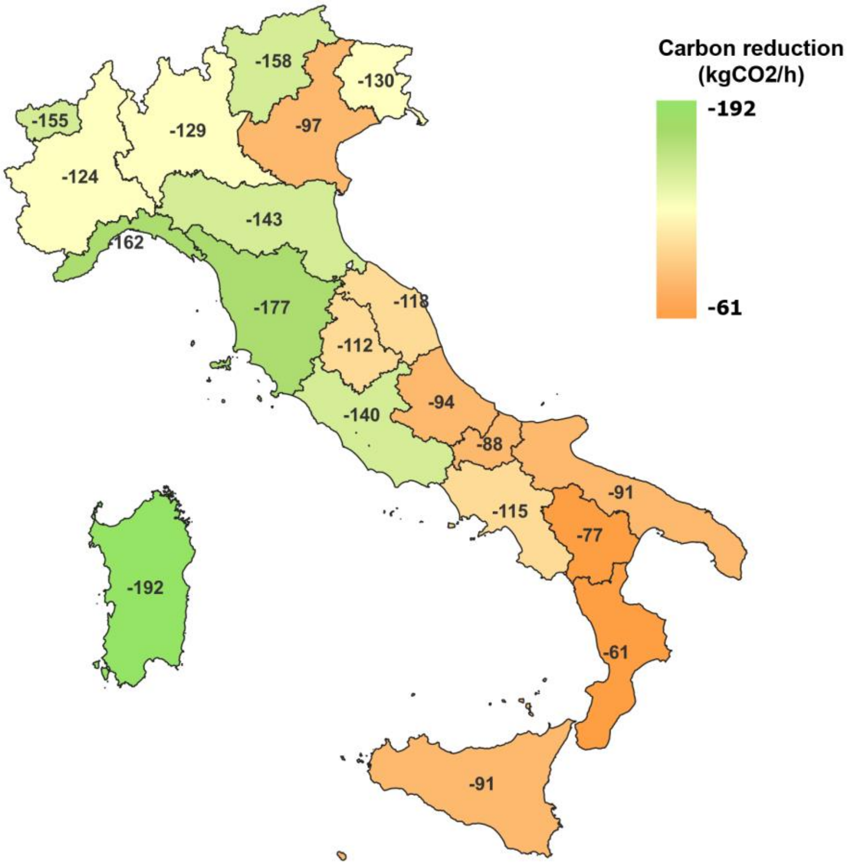

Figure 2 The figure shows the potential carbon emission reduction achievable by deploying an LFP battery (10 MW, 2h) in different regions of Italy.

the lithium-ion battery in different locations in Italy. In all regions, the effect on carbon emission is beneficial, i.e. there is a net carbon emission reduction. The greatest carbon abatement is achieved on the island of Sardinia (-192 kgCO2/h), where the presence of the storage device helps avoid wind curtailment (80.55 MWh) and reduces the need for fossil gas power plants (121.98 MWh), as detailed in Table 3.

Test case: Sardinia	
Technology	**Generation mix difference w.r.t. base case (MWh)**
Wind Onshore	80.55
Fossil Coal-derived gas	28.34
Solar	14.61
Other	13.17
Hydro Water Reservoir	13.06
Biomass	12.82
Hydro Run-of-river	-2.44
Fossil Oil	-15.33
DSR/Emb. gen.	-34.28
Fossil Gas	-121.98

Table 3 Change in generation mix w.r.t the base case (where no storage is present) due to the deployment of a lithium-ion battery (10MW, 2h) in Sardinia.

[1] The capacity is derated to account for the probability that each technology could actually contribute to system adequacy.

4. Conclusion

The current energy system requires a significant investment in large-scale energy storages to meet the net-zero target by 2050. By developing a high-fidelity network of the Italian electricity system and using actual data from the Italian wholesale market, we estimated the potential system-level impact of deploying energy storages in Italy, using a lithium-iron-phosphate battery (10MW, 2h) as reference technology. The results show that investment and management costs of these technologies are still higher than the expected benefit in terms of social welfare increase in most regions. However, the potential benefit in terms of carbon emission reduction can be significant, where the greater carbon abatement could be achieved on the island of Sardinia, as the presence of an energy storage system could help avoid wind power curtailment and the usage of fossil fuel power plants.

Acknowledgement

This work has been supported by the Recovery and Resilience Plan - Mission 4 – Subfield: "Projects presented by young researchers", project number SOE_0000029 and CUP J47G22000430001.

References

Bardwell, L., Blackhall, L., & Shaw, M. (2023). Emissions and prices are anticorrelated in Australia's electricity grid, undermining the potential of energy storage to support decarbonisation. *Energy Policy*, *173*, 113409. https://doi.org/10.1016/J.ENPOL.2022.113409

Cramton, P., Ockenfels, A., & Stoft, S. (2013). Capacity Market Fundamentals. *Economics of Energy & Environmental Policy*, *2*(2), 27–46. https://doi.org/10.5547/2160-5890.2.2.2

EntsoE. (2022). *ENTSO-E TYNDP Dataset*. https://stum.entsoe.eu/

EntsoE. (2023). *ENTSO-E System Needs Study TYNDP 2022*.

GME. (2023). *GME - Esiti dei mercati - MGP - esiti*. https://www.mercatoelettrico.org/It/Esiti/MGP/EsitiMGP.aspx

IEA. (2022). *Grid-Scale Storage*. https://www.iea.org/reports/grid-scale-storage

McKinsey. (2021). *Net-zero power Long duration energy storage for a renewable grid*.

Terna. (2022). *Capacity Market - Results of main auction with delivery period 2024*. https://www.terna.it/en/electric-system/publications/operators-news/detail/capacity-market-results-main-auction-2024

Viswanathan, V., Mongird, K., Franks, R., Li, X., Sprenkle, V., & Baxter, R. (2022). *2022 Grid Energy Storage Technology Cost and Performance Assessment*. https://www.pnnl.gov/sites/default/files/media/file/ESGC%20Cost%20Performance%20Report%202022%20PNNL-33283.pdf