OPTIBAT Study - Optimal Location of Electrical Energy Storage Systems based on Batteries

energía y sociedad

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The role of batteries in the grid

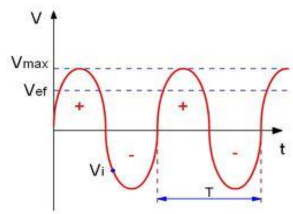
- With a **more intermittent generation mix,** the system needs **flexibility** to ensure a stable and secure electricity network. Batteries **can provide services to improve the integration of renewable energies,** load and demand management, frequency and voltage control, outage management, etc.

- **In recent years the cost of lithium-ion batteries has significantly decreased**

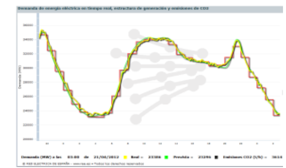
- **Great modularity and suitability for location in transmission networks, distribution networks or customer installations**

What are the optimal location and size for storage achieving the best use for the overall electrical system?

Flexibility Services that **Batteries** can provide when connected to the grid



Higher level of **coordination between energy demand and energy supply**



Load balance

Voltage & frequency control

Ancillary services, such as **voltage control, frequency regulation or active power ramps control**

Peak demand reduction

Minimize demand peaks or move the generation profile towards times of the day with higher returns

Intermintent generation management

Reduce the intermittency inherent to solar and wind energy, hence minimizing network disturbances and ensuring frequency and voltage stability

Quality of supply improvement

Batteries can **provide energy backup** during network faults **and avoid outages**

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OBJECTIVES

Determine the optimal size and location for batteries to:

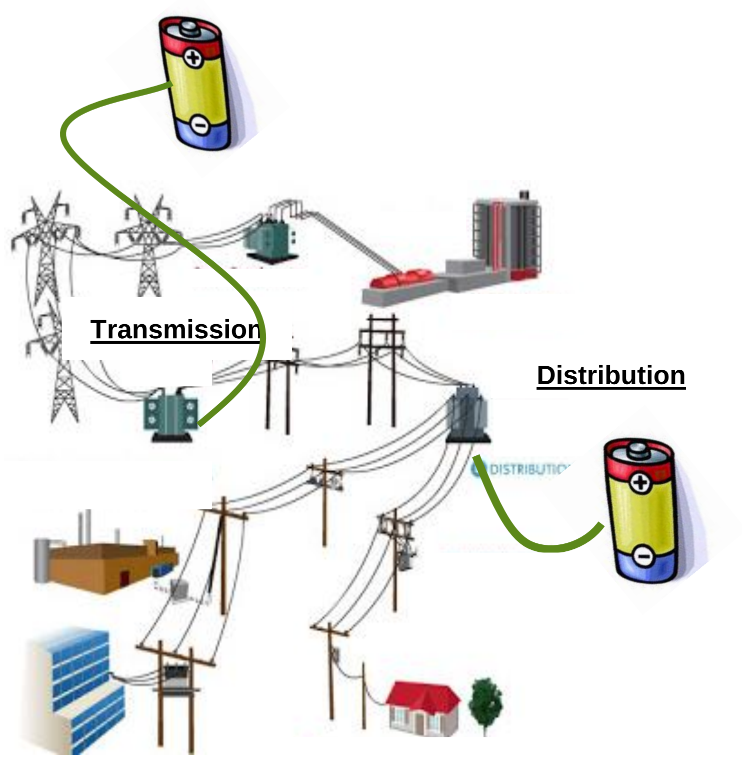
- **Provide support during outages – ENS (energy non-supplied) reduction**
- Improve load capacity factor (smoothing the demand profile)
- Manage losses
- Improve voltage profile

Considerations

- **Cost of grid connected battery storage**. Cost data used in the study comes from “Lazard’s levelized cost of energy storage” report from December 2016
- **Installation in the LV network will not be analyzed**. Refer to annex A for detailed justification
- The analysis is based on a future scenario where **renewable generation (centralized and self-consumption) and electric vehicles are assumed to experience a higher penetration than in current days**, with the aim of appreciating the benefits of installing storage in the network

The study assesses and compares the installation of batteries

The available budget to install batteries in the Murcia region has been prefixed so that the number of batteries results in a reasonable volume:



a) Transmission (HV)

The available budget is invested in the installation of batteries at 220kV or above in the Murcia region

b) Distribution (MV)

The available budget is invested in the installation of batteries in the 20kV network in the Murcia region

The study **compares** results of installing batteries in transmission and distribution

Updates provided by this study compared to others

There are multiple studies about battery optimization; this study is innovative in some aspects such as:

- Optimizing battery installation for the overall system, comparing between allocation in **Transmission (HV) and Distribution (MV)**
- The size of the network used in this assessment is larger than in other studies

Previous studies related to the optimization of storage size and locations. Refer to annex B

Methodology and Assumptions

Spanish HV transmission grid + **Murcia** network model provided by Iberdrola:

GRID	No. of networks	Buses	Generators	Loads	Transformers	Lines
Transmission	1	2674	655	989	1243	3788
Murcia MV distribution	90	31721	15388	15388	94	33327

The HV model used in the study represents the full transmission network in Spain. The MV model is limited to the 20kV network in Murcia

Step by step methodology:

1. Definition of the **2025 scenario** and contingency analysis both for the transmission and the distribution networks
2. Optimal location and size for batteries to **minimize the Energy Non-Supplied (ENS)** during outages
3. Simulation of the **battery charge/discharge regime** that optimizes the electrical system operation
4. Assessment of **results and conclusions**. Comparison between location in transmission VS. distribution

1. Scenario under study: year 2025

- 1.7 % annual demand growth (including additional demand from electric vehicles)
- New wind farms and solar farms connected to the transmission network in Murcia as per Transmission System Operator (REE) planning studies
- 20%* of PV self-consumption in distribution
- 62,000 electric vehicles (extrapolation study by Deloitte [1])

Demanda MW	Winter Peak 2014	Summer Peak 2014	Winter Peak 2025	Winter Peak 2025
Clients	992	994	1172	1185
Electric Vehicules	0	0	18	4
Total MV Demand	**992**	**994**	**1190**	**1188**
Distributed generation	235	294	235	294
PV self-consumption	0	0	0	468
Total MV Generation	**235**	**294**	**235**	**762**

* 20% of demand covered by PV self-consumption has been considered as a reasonable and realistic option

* * The different EV demand in winter and summer is based on assumed EV usage profiles

[1] Recommendations for the decarbonization of transport in Spain. http://perspectivas.deloitte.com/descarbonizacion-transporte

2. 2025 scenario contingency analysis

Estimation of demand non-supplied (DNS) resulting from outages on the transmission and distribution networks

Distribution network:

- **Winter peak**: 529 N-1 outages with 354.9 MW of demand non-supplied
- **Summer peak**: 418 N-1 outages with 285.5 MW of demand non-supplied

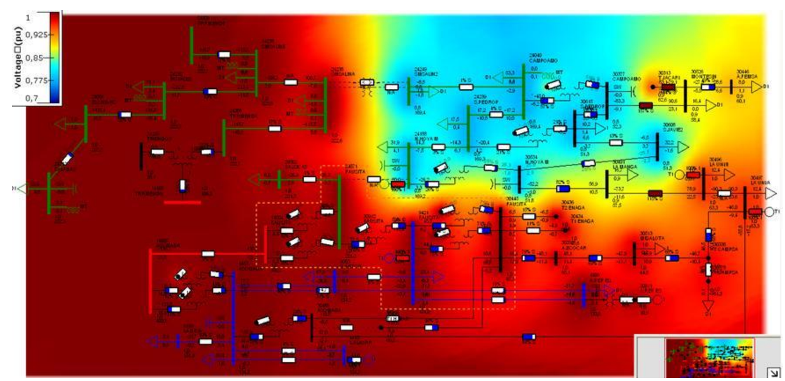
Transmission network:

Worst N-2 outage at 220 kV: opening of the 220 kV interconnector, with loss of 4 substations. It involves load shedding to prevent voltage collapse:

- **Winter peak**: 51.6 MW of demand non-supplied
- **Summer peak**: 44.4 MW of demand non-supplied

Location of distribution outages (Winter peak)


Murcia 220kV transmission path affected by N-2 outage


Voltage colour map after N-2 transmission outage

3. Optimal location of batteries

- Budget availability to install batteries until 2025 assumed to be €100m
- Assumptions on average outage time based on location; batteries should be capable of supplying the demand non-supplied during that time:
  - Distribution overhead line outage: 3 hours
  - Distribution underground line outage: 9 hours
  - Transmission overhead line outage : 9 hours
- Battery sizing and unit cost [2]:
  - Distribution overhead line outages: power/energy 1:3. Cost 232.6 €/kWh
  - Distribution underground line outages: power/energy 1:9. Cost 212.4 €/kWh
  - Transmission overhead line outages: power/energy 1:9. Cost 212.4 €/kWh
- Optimization of batteries location in the transmission network vs. the distribution network:
  - Choosing the most effective battery sizes to outweigh outages
  - Choosing the most effective battery locations to offset all outages under consideration

Optimal location at distribution:

- ✓ 63 batteries: 76.5 MW / 433.5 MWh
- ✓ Total cost: € 99.81m

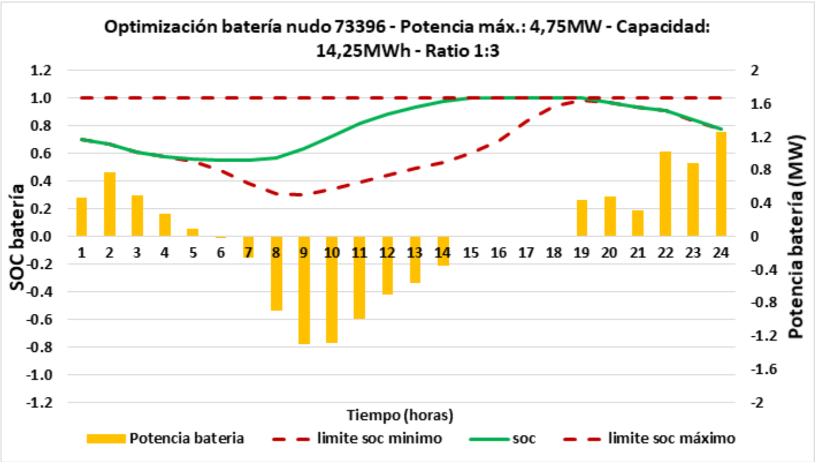
Optimal location at transmission :

- ✓ 2 batteries (at Hoya Morena 220 kV and San Pedro del Pinatar 220 kV): 52 MW / 468 MWh
- ✓ Total cost: € 99.4m

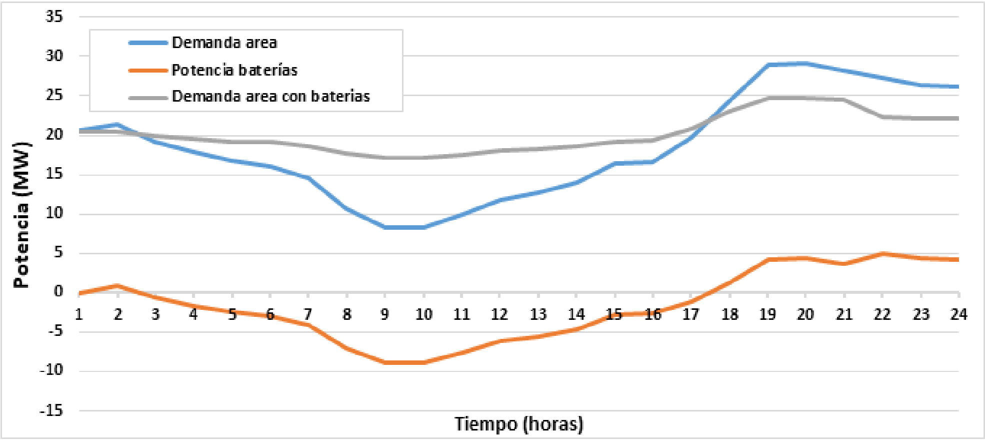
[2] Data from report *Lazard's levelized cost of energy storage. December 2016. Extrapolation to 2025 (Exchange rate 1.09 €/$*

4. Optimal management of charge/discharge operation

- Simulation of installed batteries in order to achieve:
  - Batteries in distribution: optimization of the load profile at the HV/MV transformer feeding the section of the network with batteries
  - Batteries in transmission: optimization of the overall load profile in the Murcia network
- Operational restriction:
  - The state of charge of the batteries is managed so that they can cope with outages (power supply affected by the outage for the whole outage duration)



Effect of battery dispatch in distribution: Battery dispatch in bus 73396. Day in August 2025



Effect of battery dispatch in distribution: power demand in transformer 3 San Félix. Day in August 2025

5. Results analysis

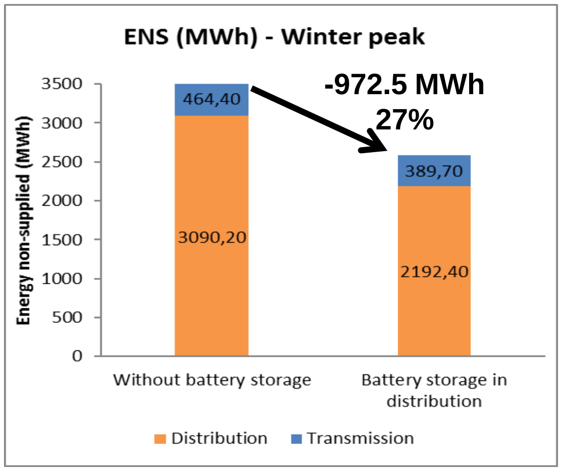
- Improvement in quality of supply (reduction in disconnected load during outages) [3]:
  - For **batteries installed in the distribution network** (total storage: 76.5 MW / 433.5 MWh):
    - Better performance for outages on the distribution network:
      - Reduction of **103.1 MW of DNS and 897.8 MWh of ENS** during the winter peak
      - Reduction of **51.9 MW of DNS and 448.2 MWh of ENS** during the summer peak
    - Better performance for outages on the transmission network:
      - Reduction of **8.3 MW of DNS and 74.7 MWh of ENS** during both the winter and the summer peaks
  - For **batteries installed in the transmission network** (total storage: 52 MW / 468 MWh):
    - No change in performance for outages on the distribution network
    - All issues originated by outages on the transmission network are resolved:
      - Reduction of **51.6 MW of DNS and 464.4 MWh of ENS** during the winter peak
      - Reduction of **44.4 MW of DNS and 399.6 MWh of ENS** during the summer peak

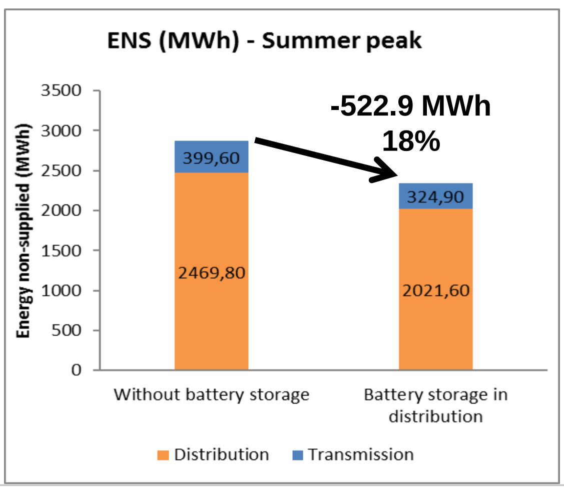
Batteries are far more efficient when installed at the distribution level

[3] Deterministic calculation. See Annex C

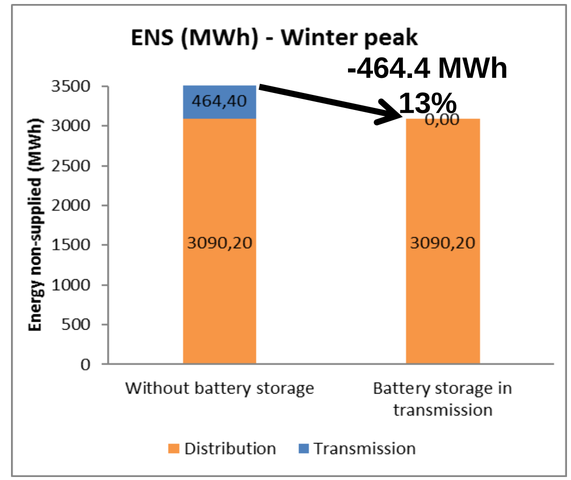
5. Results analysis – Quality of supply

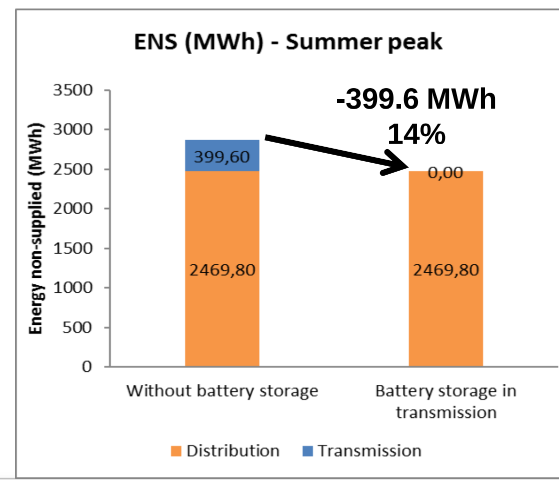
63 batteries in Distribution
76.5 MW / 433.5 MWh





2 batteries in Transmission
52 MW / 468 MWh

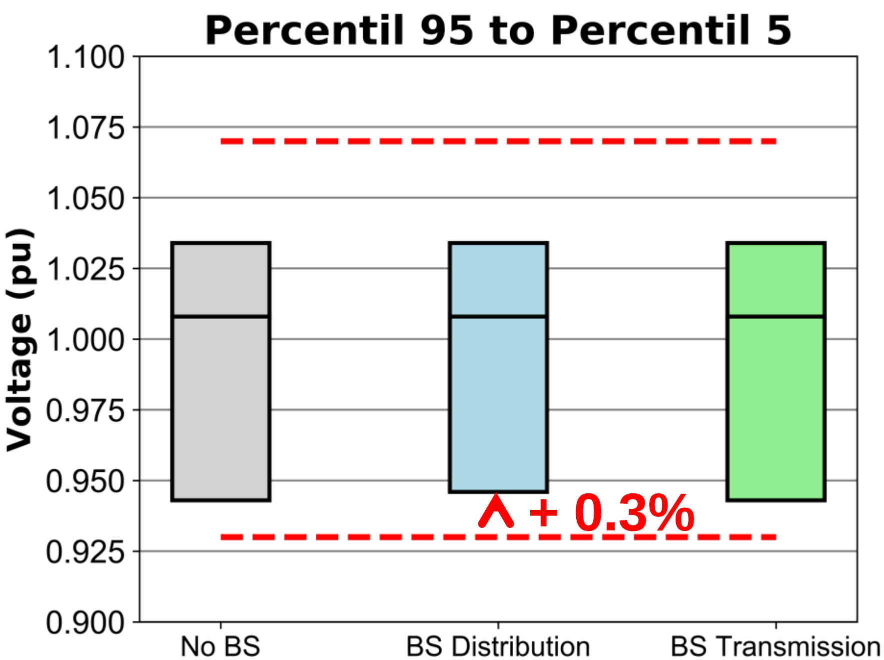




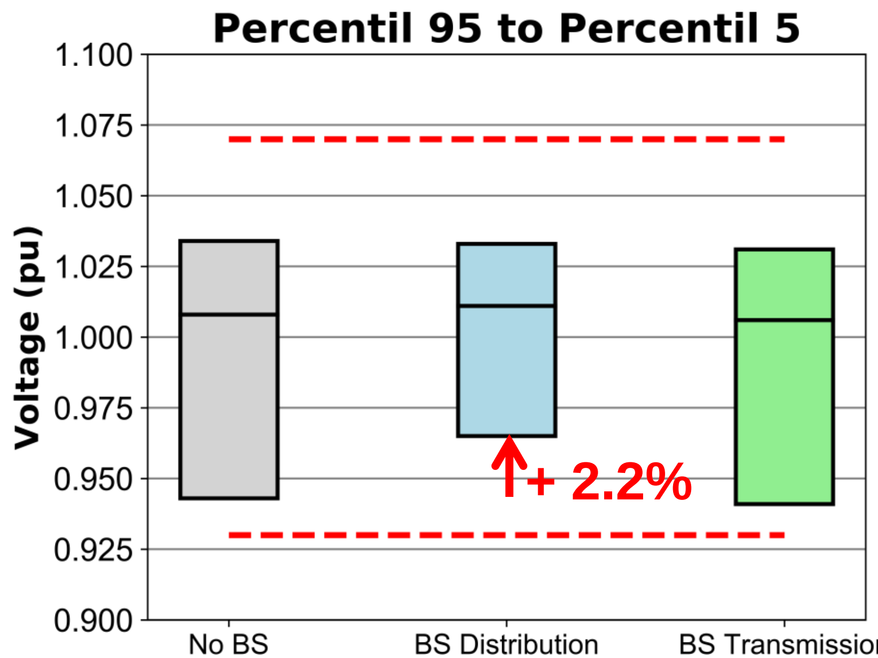
Batteries are far more efficient when installed at the distribution level

5. Results analysis – Distribution bus voltages

Batteries without voltage control

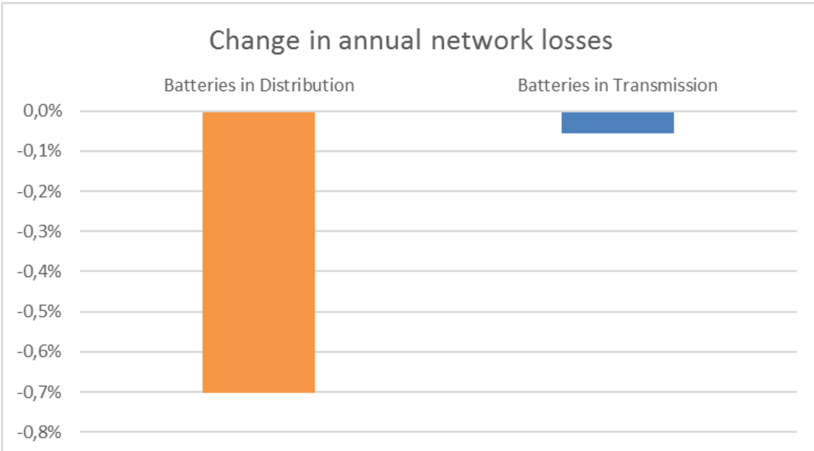


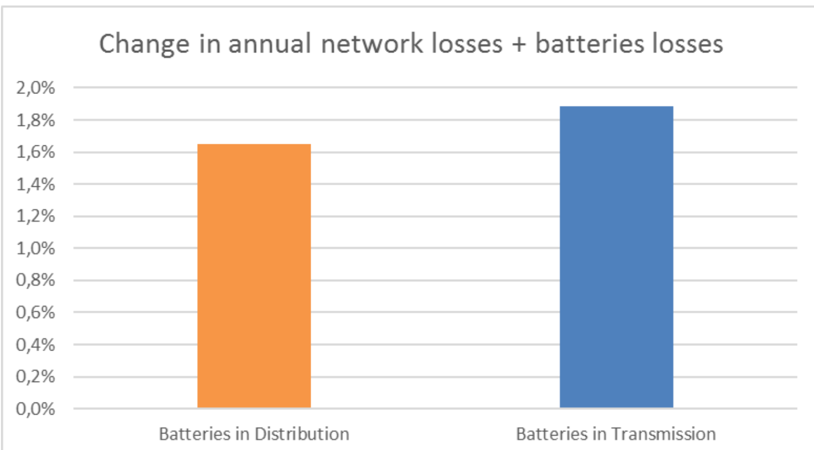
Batteries with voltage control

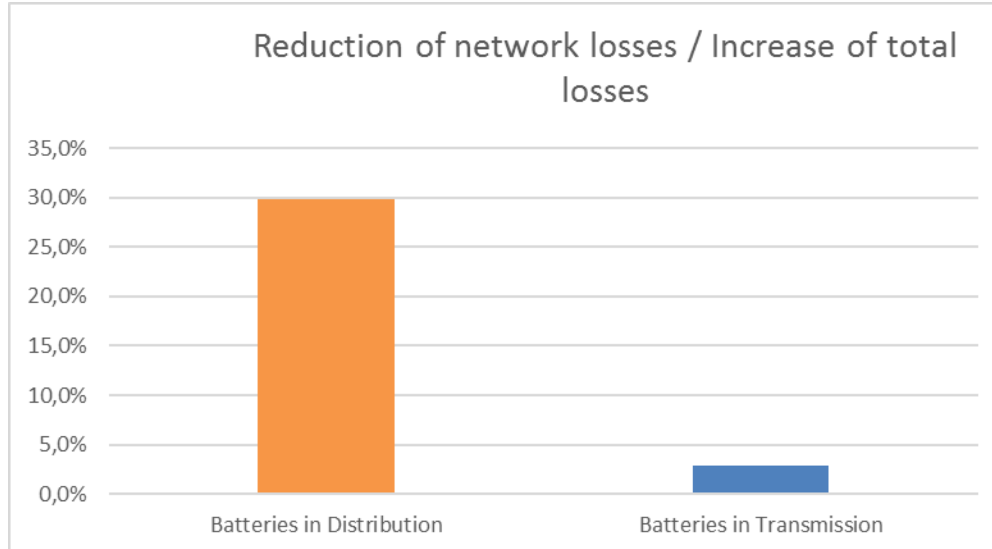


Batteries located in the distribution network improve the voltage profile. The influence is more significant when the batteries operate with voltage control

5. Results analysis – Losses

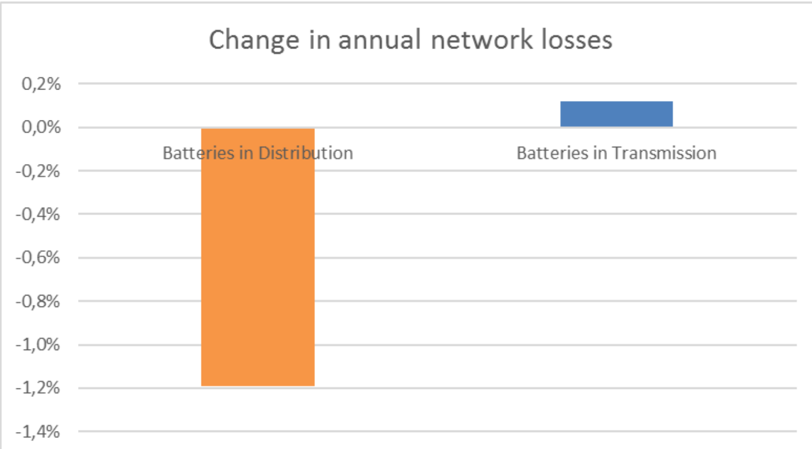


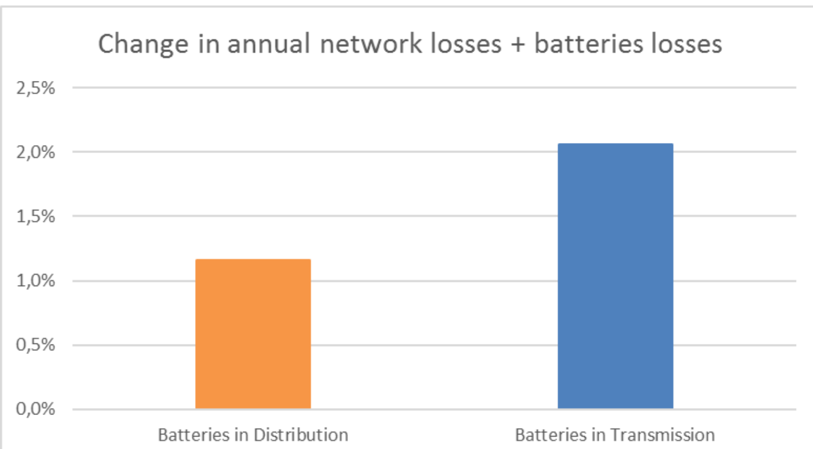


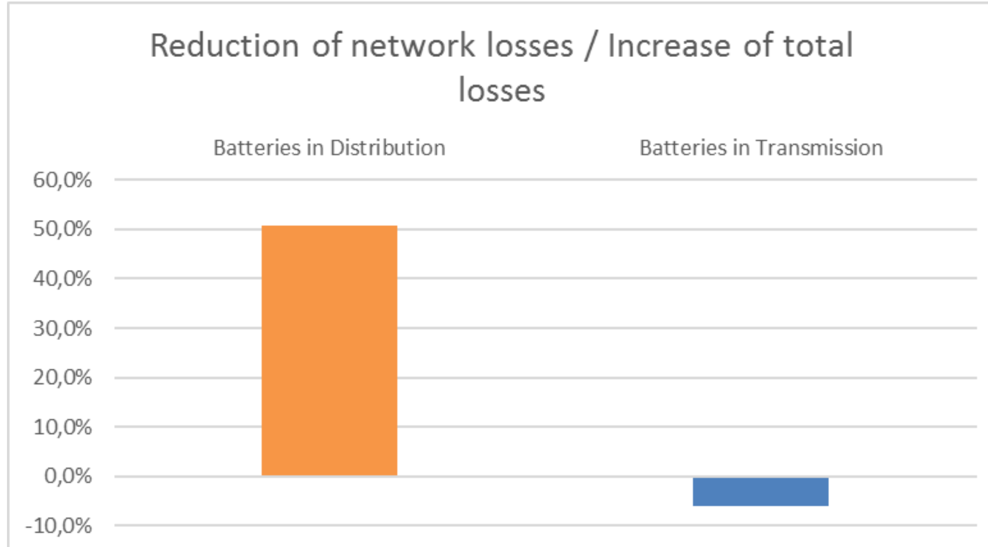


- Influence on network losses is not significant due to the low volume of battery storage in relation to demand
- Batteries increase total losses due to their charge/discharge losses
- If charge/discharge efficiency improves, batteries located in distribution are closer to total loss reduction achievement than batteries in transmission

5. Results analysis – Losses with voltage control







- Voltage control improves the effectiveness of batteries for reducing network losses when installed at the distribution level

Location in transmission VS distribution

- Batteries **installed in the distribution network provide a better solution** to reduce unsupplied demand under outage conditions.
- Batteries **installed in the transmission network provide no support** under distribution outages leading to loss of supply.
- Batteries installed in the distribution network achieve an ENS reduction 2 times higher than batteries installed in the transmission network.
- Annual energy losses experience a greater reduction when batteries are installed in the distribution network than in the transmission network. Although losses increase for both cases when the battery consumption is taken into account.
- Batteries installed in the distribution network achieve a better voltage profile.

Reasons to Discard Analysis Behind The Meter (BTM)

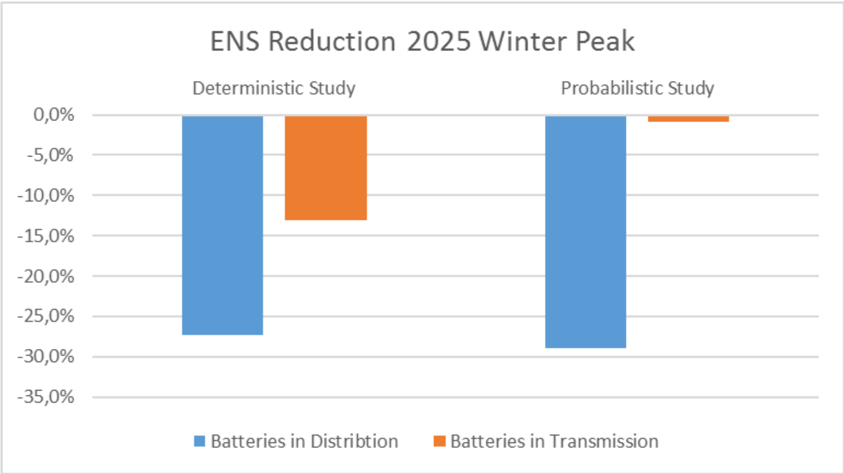
- The battery unit costs are higher
- The communications required to manage a large volume of batteries have a higher cost and are less reliable
- The availability of energy stored in batteries depends on the customer preferences, and hence is not totally guaranteed
- For a fault on the LV network, all batteries connected to the faulty section must be disconnected offering no support to the network, although they can supply the customer installation
- The average interruption time for an LV customer under MV and HV faults is higher than under LV faults. Moving the batteries from the MV network to the LV network does not significantly improve the quality of supply

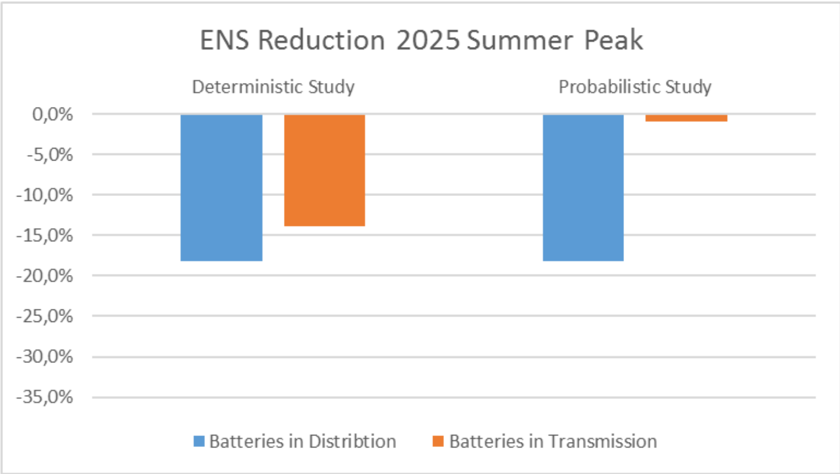
Previous studies related to the optimization of storage size and locations

- S.R. Deeba, R. Sharma, T.K. Saha, D. Chakraborty, A. Thomas, *Evaluation of technical and financial benefits of battery-based energy storage systems in distribution networks*, IET Renewable Power Generation, Vol. 10, N. 8
- E. Reihania, M. Motalleba, R. Ghorbania, L.S. Saoud, *Load peak shaving and power smoothing of a distribution grid with high renewable energy penetration,* Renewable Energy Volume 86, February 2016, pp. 1372-1379
- Y. Yang, H. Li, A. Aichhorn, J. Zheng, M. Greenleaf, *Sizing Strategy of Distributed Battery Storage System With High Penetration of Photovoltaics for Voltage Regulation and Peak Load Shaving,* IEEE Transactions on Smart Grid, Vol. 5, N. 2
- Rocky Mountain Institute, *The Economics of Battery Energy Storage*
- R.B. Bass, J. Carr, J. Aguilar, K. Whitener, *Determining the Power and Energy Capacities of a Battery Energy Storage System to Accommodate High Photovoltaic Penetration on a Distribution Feeder,* IEEE Power and Energy Technology, Vol. 3, N. 3

ENS – Deterministic VS Probabilistic study

	2025 Winter Peak			2025 Summer Peak		
	DNS (MW)	ENS Det (MWh)	ENS Prob (MWh)	DNS (MW)	ENS Det (MWh)	ENS Prob (MWh)
No Batteries	406,6	3554,6	2871,6	330,4	2869,4	2353,3
Batteries in Distribution	295,2	2582,1	2040,4	270,2	2346,5	1926,1
Batteries in Transmission	355,0	3090,2	2847,4	286,0	2469,8	2332,5





Considering outage failure rates reinforces the main conclusion of the study. Batteries are far more efficient when installed at the distribution level