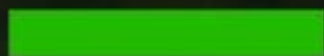




LAND OF THE CURIOUS



Hydrogen Research Forum Finland: Annual Seminar 2024

Baseload hydrogen supply from an Off-Grid Solar PV-Wind Power-Battery-Water electrolyzer plant

Simultaneous Optimization of Component Capacities and System Control

Alejandro Ibáñez-Rioja, Pietari Puranen, Lauri Järvinen, Antti Kosonen, Katja Hynynen, Vesa Ruuskanen, Jero Ahola
and Pertti Kauranen

Green hydrogen production system



Solar PV



Battery Energy Storage System (BESS)



Wind farm

Electricity



Alkaline Water Electrolyzer (AWE) plant

H₂



H₂ compressor



H₂ storage (Rock/Salt cavern)

H₂
End-user

Constant H₂ demand

■ Optimized variables (x_1 to x_{12}) to minimize Levelized Cost Of Hydrogen (LCOH₂) for 30-year lifetime

- Control parameters (x_1 to x_8)
- Solar PV peak power capacity (x_9)
- Wind farm nominal capacity (x_{10})
- BESS energy capacity (x_{11})
- H₂ Storage volume capacity (x_{12})

■ Sensitivity analysis

- H₂ end-user demand (kg/min): 4, 8, 12, 16, 20
- Components price for years: 2025 2040
- Discount rates (%): 3, 5, 7
- H₂ storage geology: Rock, Salt

■ AWE + Compressor is fixed to 100 MW

System description

■ Solar PV

- *Data collected from southeastern Finland 2021-5min resolution*
- *Degradation included*
- *Peak power capacity is optimized*

■ Wind farm

- *Data collected from southeastern Finland 2021-10min resolution*
- *Nominal capacity is optimized*

■ Battery Energy Storage System

- *Round trip efficiency: 85%*
- *Model based on LFP chemistry*
- *Degradation and replacement included*
- *Capacity is optimized*

■ Alkaline water Electrolyzer + Compressor

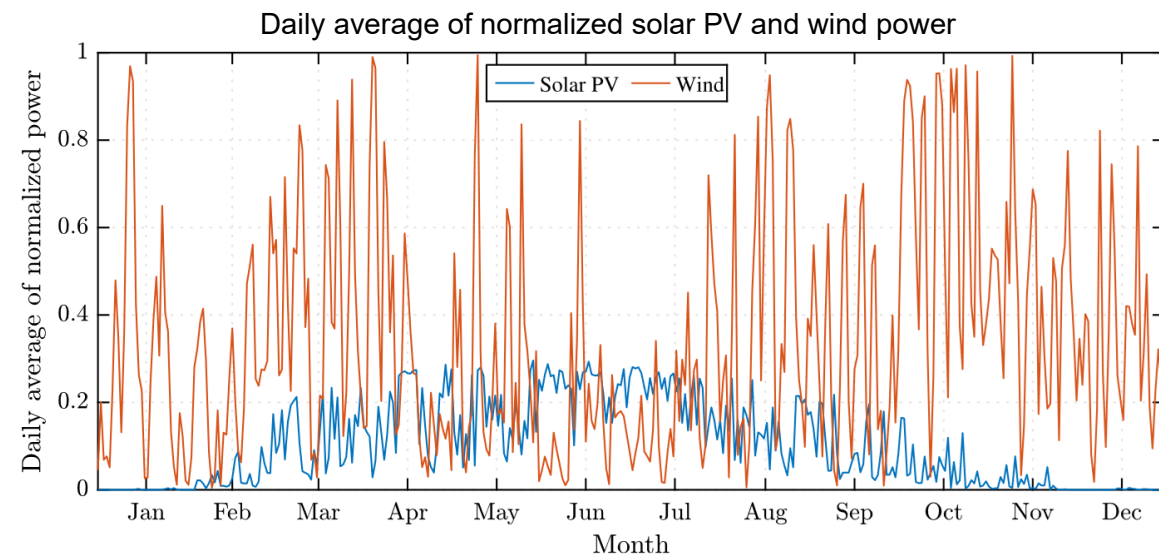
- *Fixed nominal power capacity: 100MW*
- *Minimum power: 20% nominal capacity*
- *Degradation and replacement included*
- *Startups and shutdowns time included*

■ Hydrogen storage

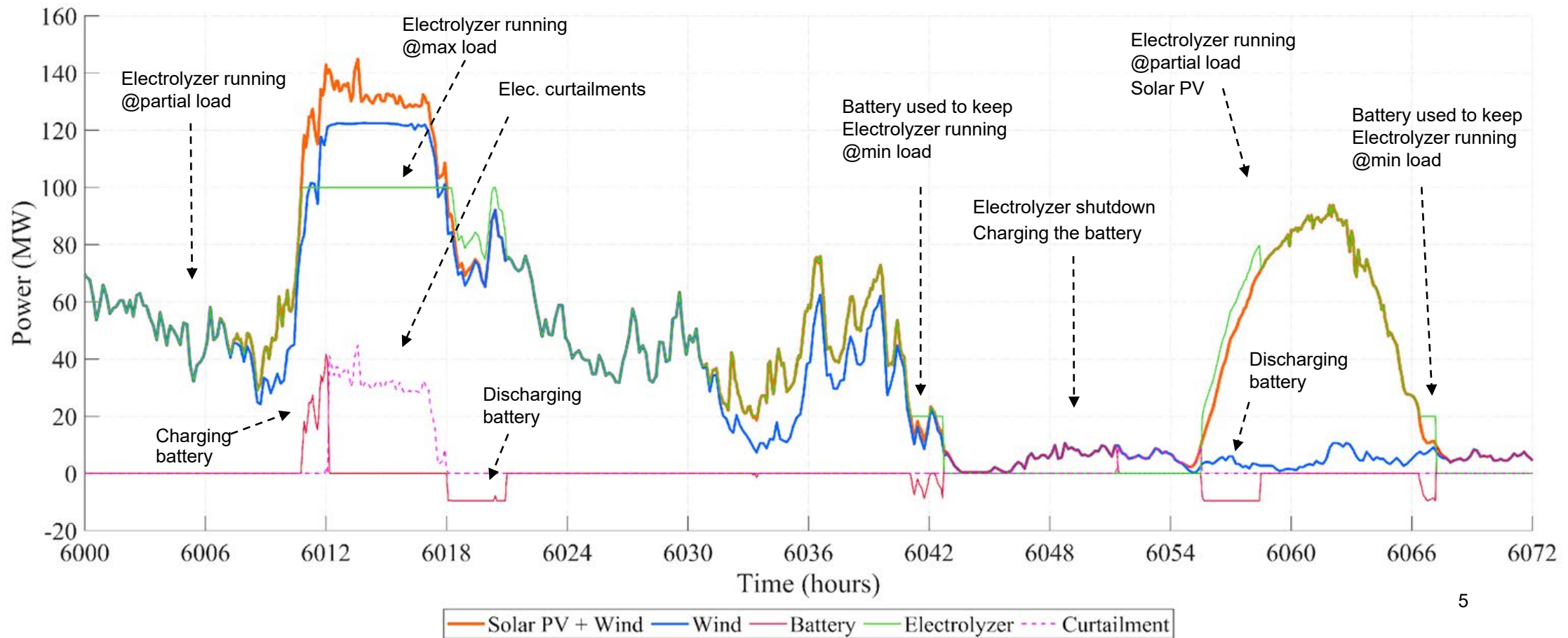
- *Rock and salt caverns*
- *10-230 bar (Rock), 60-180 bar (Salt)*
- *Volume is optimized*

■ Finite-state machine basis control

- *4 different states*
- *8 variables optimized*

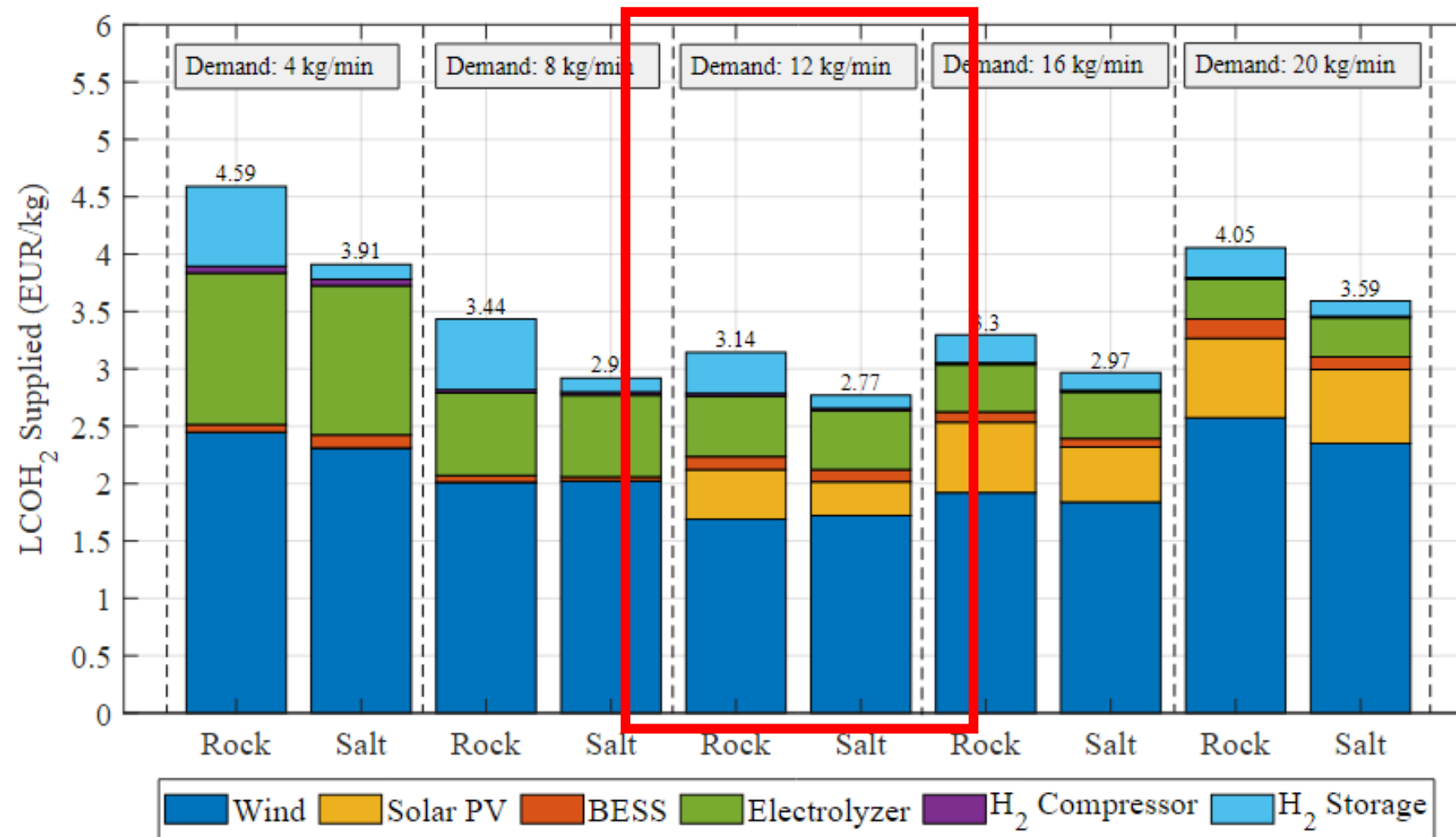


Optimized Control

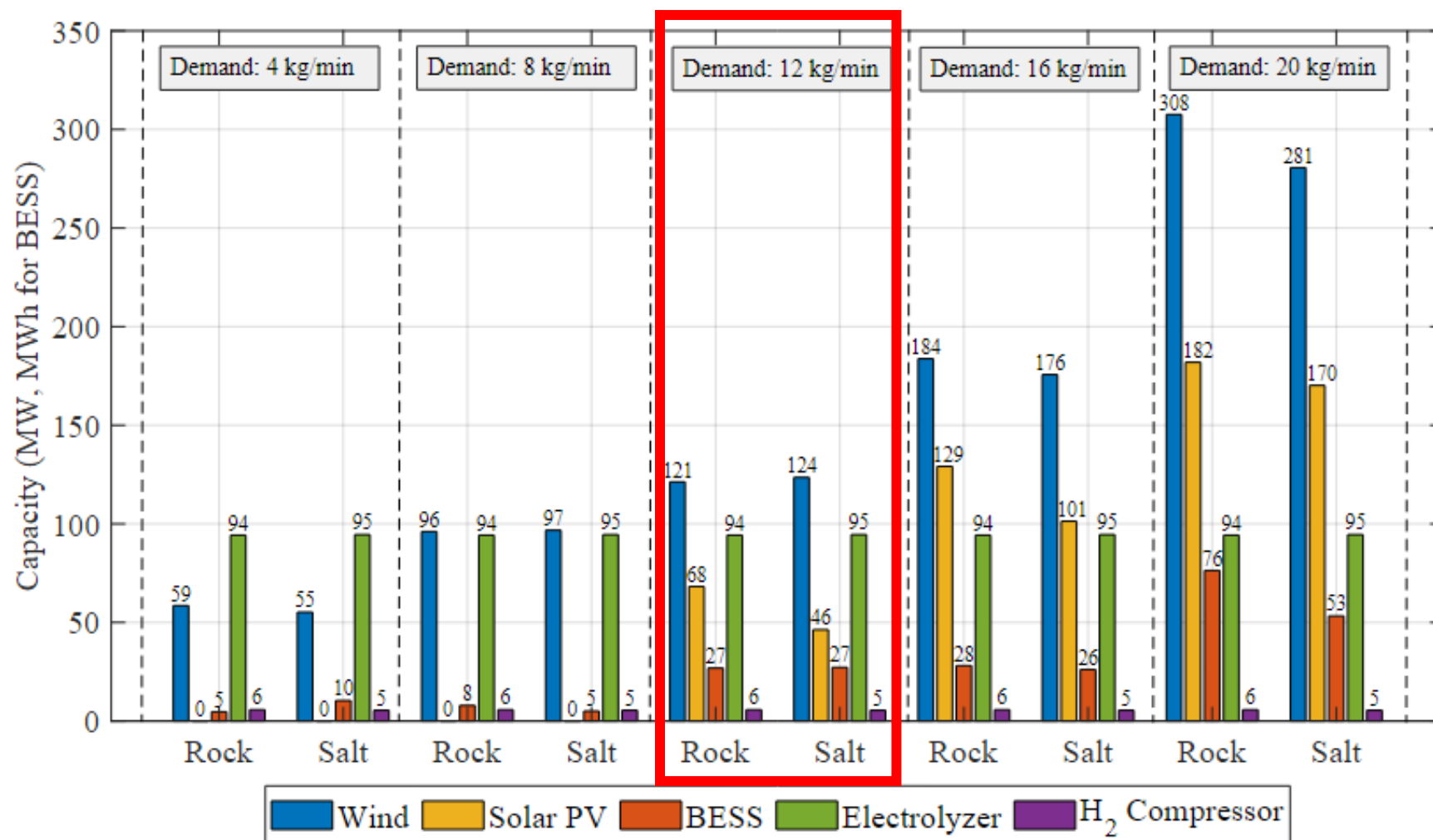


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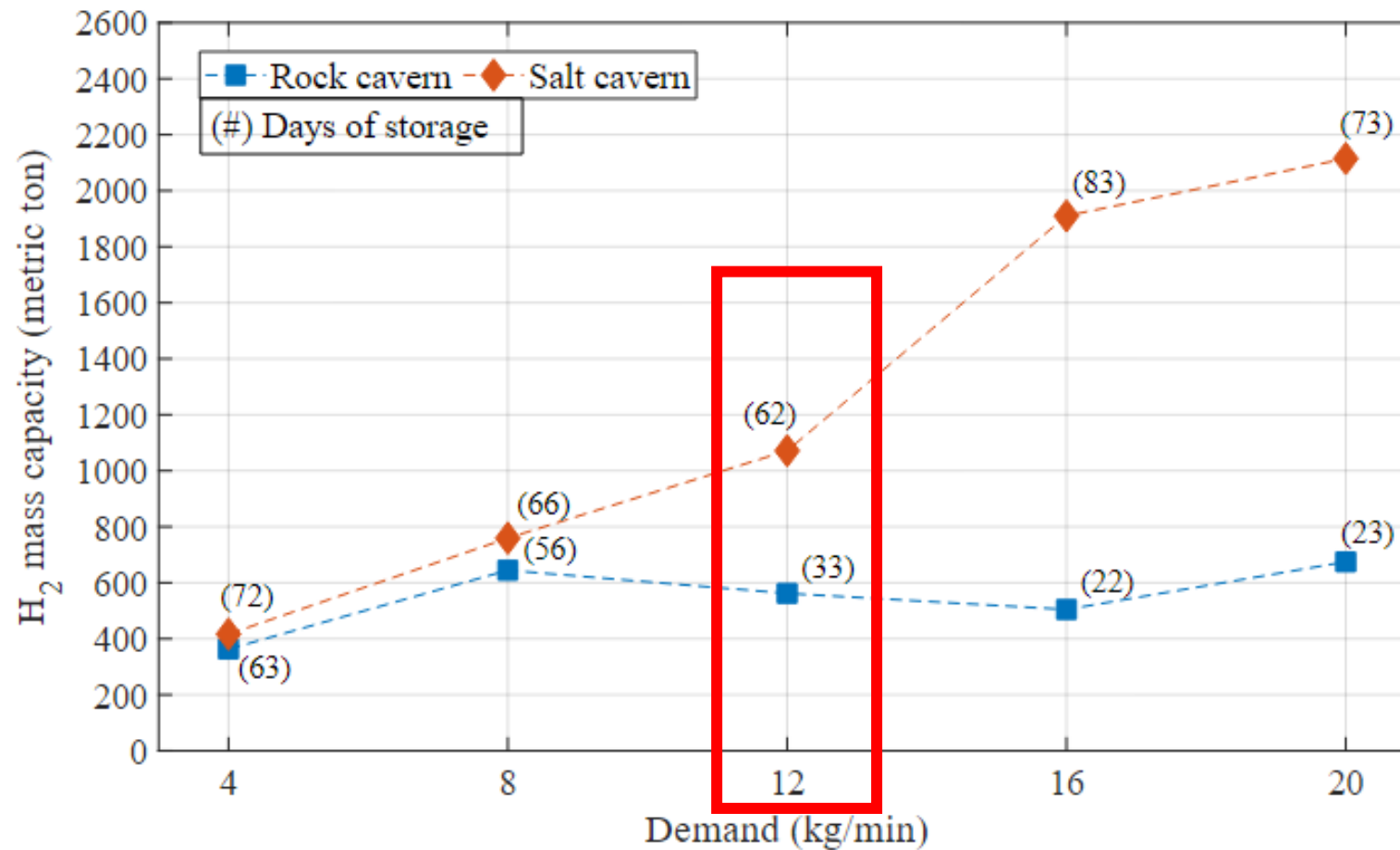
Results: Levelized Cost Of Hydrogen (LCOH₂)



Results: Optimal capacities

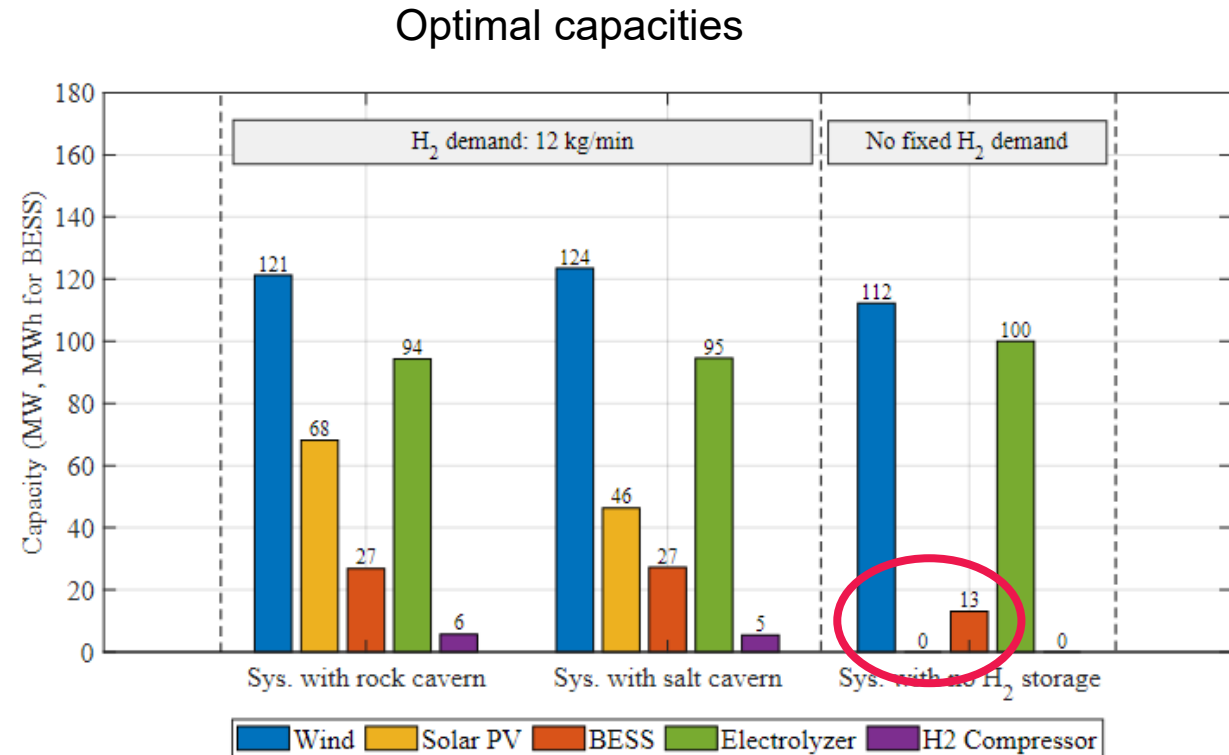
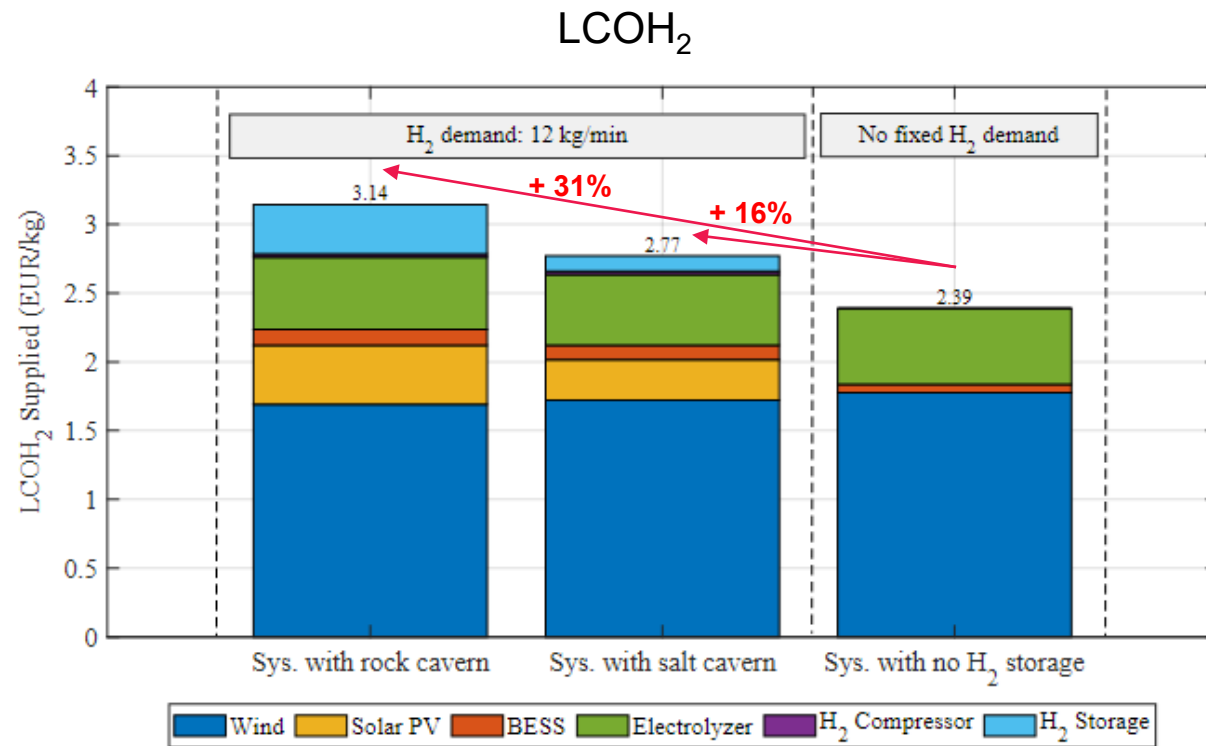


Results: Optimal hydrogen storage capacity

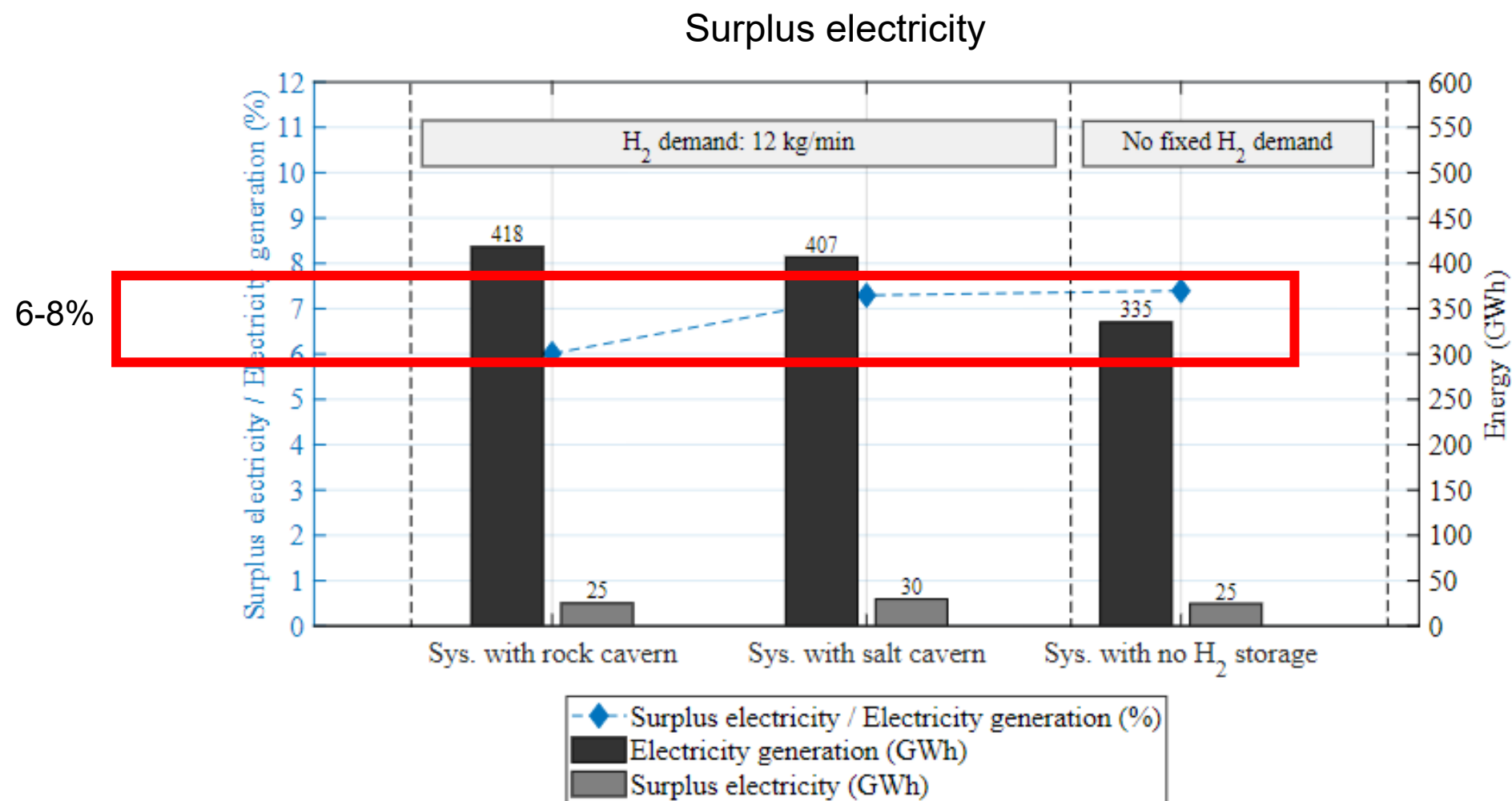


Comparison with no-fixed-demand case

- Only wind power + AWE for no-fixed-demand case

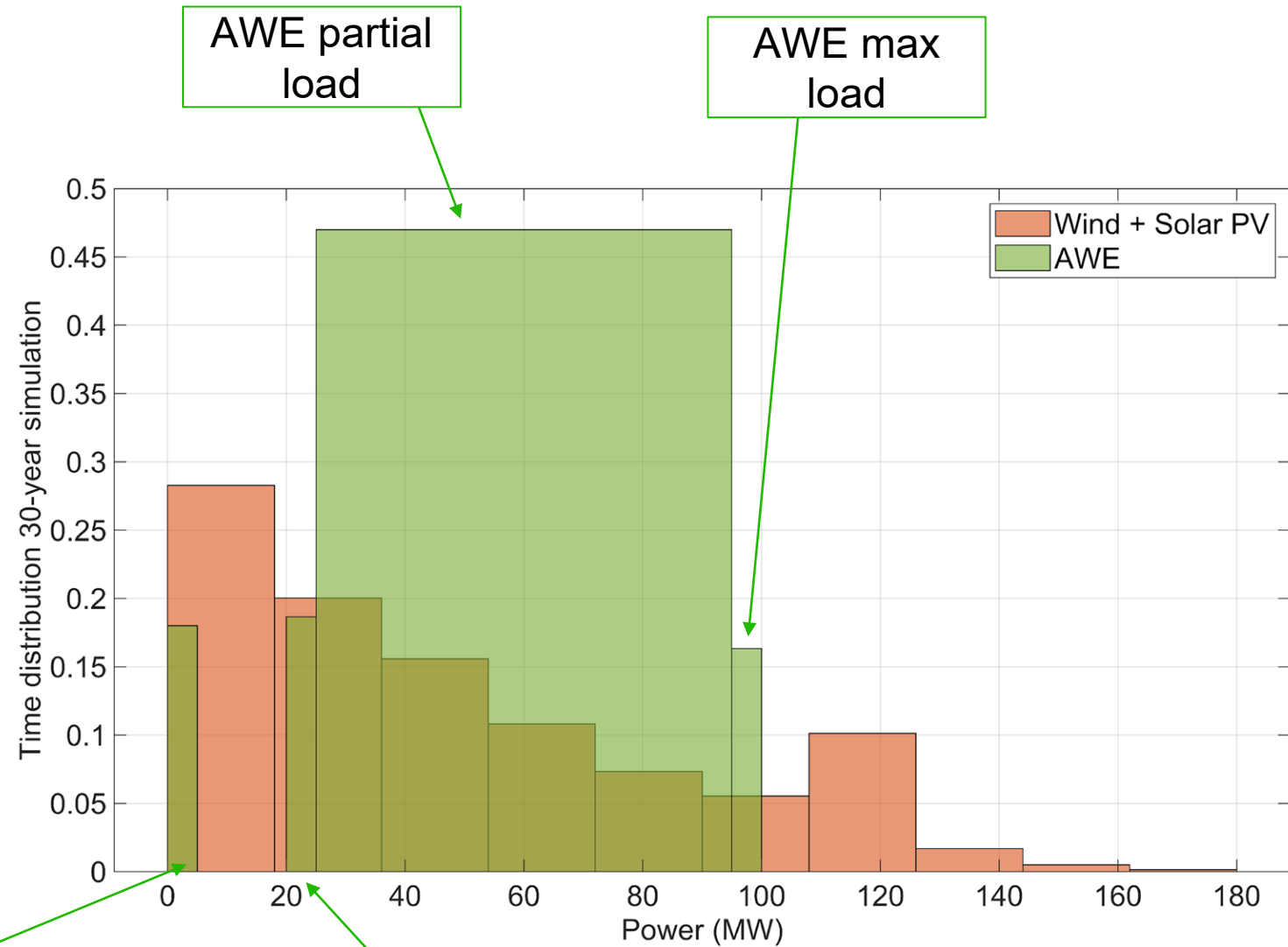


Comparison with no-fixed-demand case



Power histogram

- Wind farm: 125 MW
- Solar PV: 45 MWp
- AWE+C: 100 MW



AWE
Shutdown

AWE min load

AWE partial
load

AWE max
load

Conclusions

- For a 100 MW AWE + Compressor → ~12 kg/min H₂ demand
- Larger H₂ storage volume for salt caverns
- Fixed H₂ demand → Includes Solar PV in the optimal configuration
- Fixed H₂ demand → +0.38 €/kg (salt) and +0.75 €/kg (rock)
- AWE operating at partial loads (+45% time), BESS to avoid shutdowns
- Electricity curtailments → ~6-7%, grid connection? Sell surplus electricity?
- Flexibility in the H₂ demand

Publications

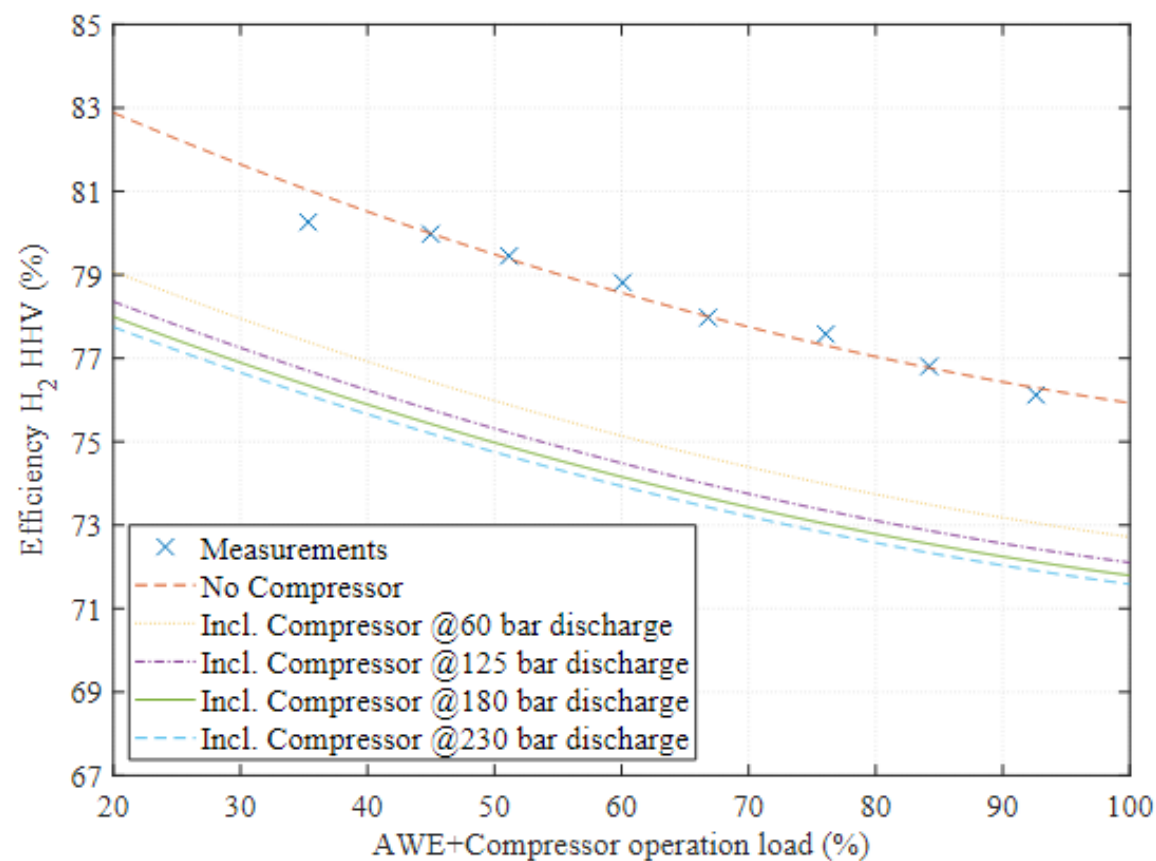
- Ibáñez-Rioja A., Puranen P., Järvinen L., Kosonen A., Ruuskanen V., Ahola J., et al. *Simulation methodology for an off-grid solar–battery–water electrolyzer plant: simultaneous optimization of component capacities and system control*. Applied Energy, 0306-2619, 307 (2022), <https://doi.org/10.1016/j.apenergy.2021.118157>
- Ibáñez-Rioja A., Järvinen L., Puranen P., Kosonen A., Ruuskanen V., Ahola J., et al. *Off-grid solar PV–wind power–battery–water electrolyzer plant: Off-grid solar PV–wind power–battery–water electrolyzer plant: Simultaneous optimization of component capacities and system control*. Applied Energy 345, 121277 (2023), <https://doi.org/10.1016/j.apenergy.2023.121277>
- Ibáñez-Rioja A., Puranen P., Järvinen L., Kosonen A., Ruuskanen V., Ahola J., et al. *Baseload hydrogen supply from an off-grid solar PV-wind power-battery- water electrolyzer plant*. **Under review** in Energy journal. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4969305

Thank you!

Questions? Comments?

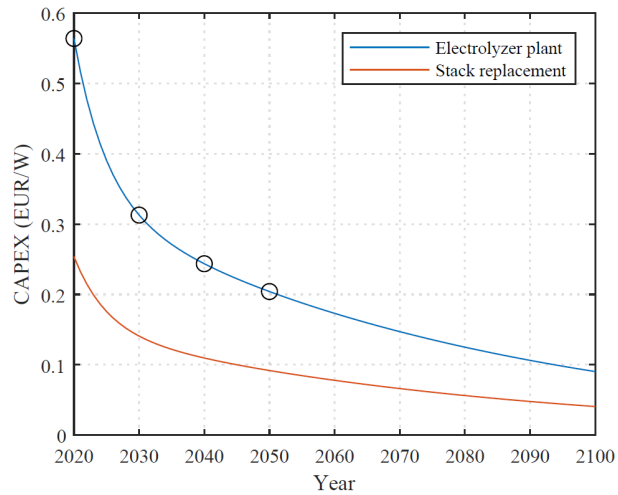


Efficiency Atmospheric Alkaline Water Electrolyzer

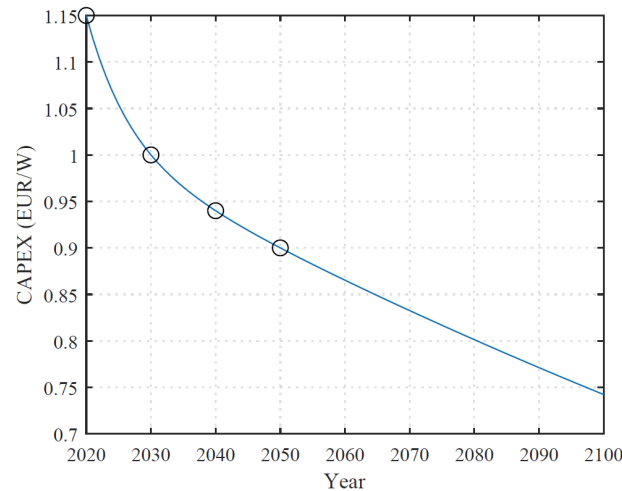


Components CAPEX and Learning curves

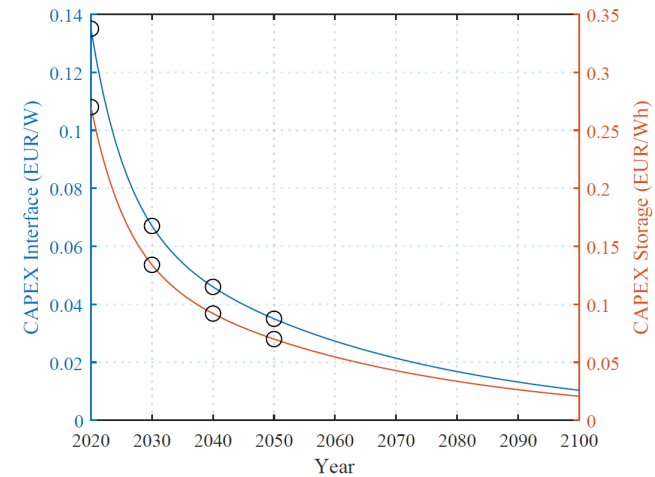
AWE



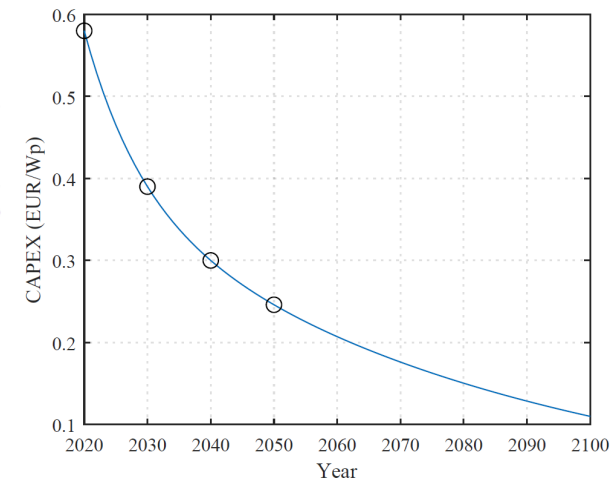
Wind



BESS



Solar PV



- Rock Cavern: 42.3 €/kg
- Salt Cavern: 7.02 €/kg
- Compressor: 0.21 €/W