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8.8.2023 – 2nd Seminar in Hydrogen Research Forum Finland – System level changes in hydrogen transition

Solar- and wind-based hydrogen generation in off-grid

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From electricity to chemical energy – Hydrogen production by alkaline water electrolyzer

Fig. 3x3 MW alkaline water electrolyzer (AWE).

Summary:

- Located in Kokkola, Finland
- Power-to-Hydrogen: 1800 Nm^3/h (H_2)
- 3x3 MW pressurized alkaline water electrolyzers, 3x600 Nm^3/h, 16 bar (H_2)
- The main use of H_2 plant is at nearby Cobalt plant, hydrogen delivery by a pipeline
- The rest of H_2 compressed to 200–300 bar and stored in bottles for delivery with trucks

G. Sakas, A. Ibáñez-Rioja, V. Ruuskanen, A. Kosonen, J. Ahola, O. Bergmann, Dynamic energy and mass balance model for an industrial alkaline water electrolyzer plant process, Int. J. Hydrogen Energy 47 (7) (2022) 4328–4345, https://doi.org/10.1016/j.ijhydene.2021.11.126

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Off-grid solar PV–wind power–battery–water electrolyzer plant: Simultaneous optimization of component capacities and system control

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ABSTRACT

Green hydrogen production systems will play an important role in the energy transition from fossil-based fuels to zero-carbon technologies. This paper investigates a concept of an off-grid alkaline water electrolyzer plant integrated with solar photovoltaic (PV), wind power, and a battery energy storage system (BESS). The operation of the plant is simulated over 30 years with 5 min time resolution based on measured power generation data collected from a solar photovoltaic installation and a wind farm located in southeastern Finland. Levelized cost of hydrogen (LCOH) is calculated based on the capital expenditures (CAPEX), the operating expenses (OPEX), and the respective learning curves for each of the components. Component degradation and replacements during the operational lifetime are included in the model, and the capacity of the components and the system control are simultaneously optimized to obtain the minimum LCOH. A sensitivity analysis performed over different installation years and discount rates reveals that for the off-grid alkaline system, the implementation of a wind farm as the sole power supply is the most economical solution until the installation years 2035–2040. Solar PV and a BESS are found to increase the full-load hours of the electrolyzer and reduce the electricity curtailed in the off-grid plant to less than 8%. However, with the current component prices and the climate in the studied region, they are not economically beneficial. It is found that the cost of hydrogen can be reduced to 2 €/kg by the year 2030.

A. Ibáñez-Rioja, L. Järvinen, P. Puranen, A. Kosonen, V. Ruuskanen, K. Hynynen, J. Ahola, P. Kauranen, Off-grid solar PV–wind power–battery–water electrolyzer plant: Simultaneous optimization of component capacities and system control, *Appl. Energ.* 345 (2023), Article 121277. https://doi.org/10.1016/j.apenergy.2023.121277.

See also press release: https://www.lut.fi/en/news/wind-most-cost-effective-power-source-hydrogen-economy-southeast-finland.

System description (1/2)

- Off-grid Solar PV + Wind Power + Battery Energy Storage + 100 MW Alkaline Water Electrolyzer
- 30 years plant simulation with 5 min resolution

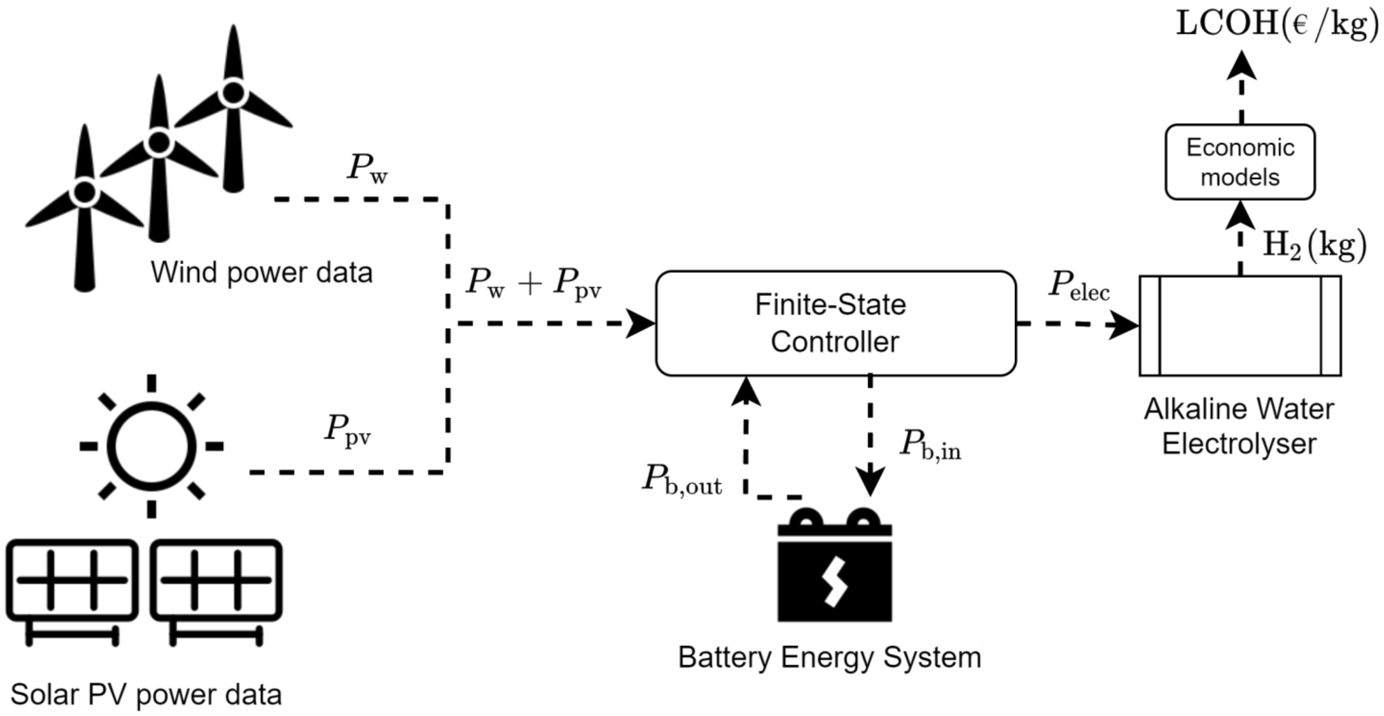


Fig. Simplified flowchart of the off-grid green hydrogen production system.

System description (2/2)

- Solar PV
  - Data collected from southeastern Finland 2021-5min resolution
  - Degradation included
  - Peak power capacity is optimized
- Wind power
  - Data collected from southeastern Finland 2021-10min resolution
  - Nominal capacity is optimized
- Battery Energy Storage System
  - Round trip efficiency: 92%
  - Degradation and replacement included
  - Capacity is optimized
- Alkaline water Electrolyzer
  - Fixed nominal power capacity: 100MW
  - Minimum power: 20% nominal capacity
  - Degradation and replacement included
- Finite-state machine basis control
  - 8 variables optimized

State	Electrolyzer power	Description
1	0	*Elec off*
2	$max\{x_8 \cdot P_{\mathrm{PV_i+W}_i}, P_{\mathrm{e,min}}\}$	*Electrolyzer following solar PV+Wind power and charging Battery*
3	$max\{P_{\mathrm{PV_i+W}_i}, P_{\mathrm{e,min}}\}$	*Electrolyzer following Solar PV+Wind Power*
4	$P_{\mathrm{e,nominal}}$	*Electrolyzer at nominal power*

Wind and solar power production in this study

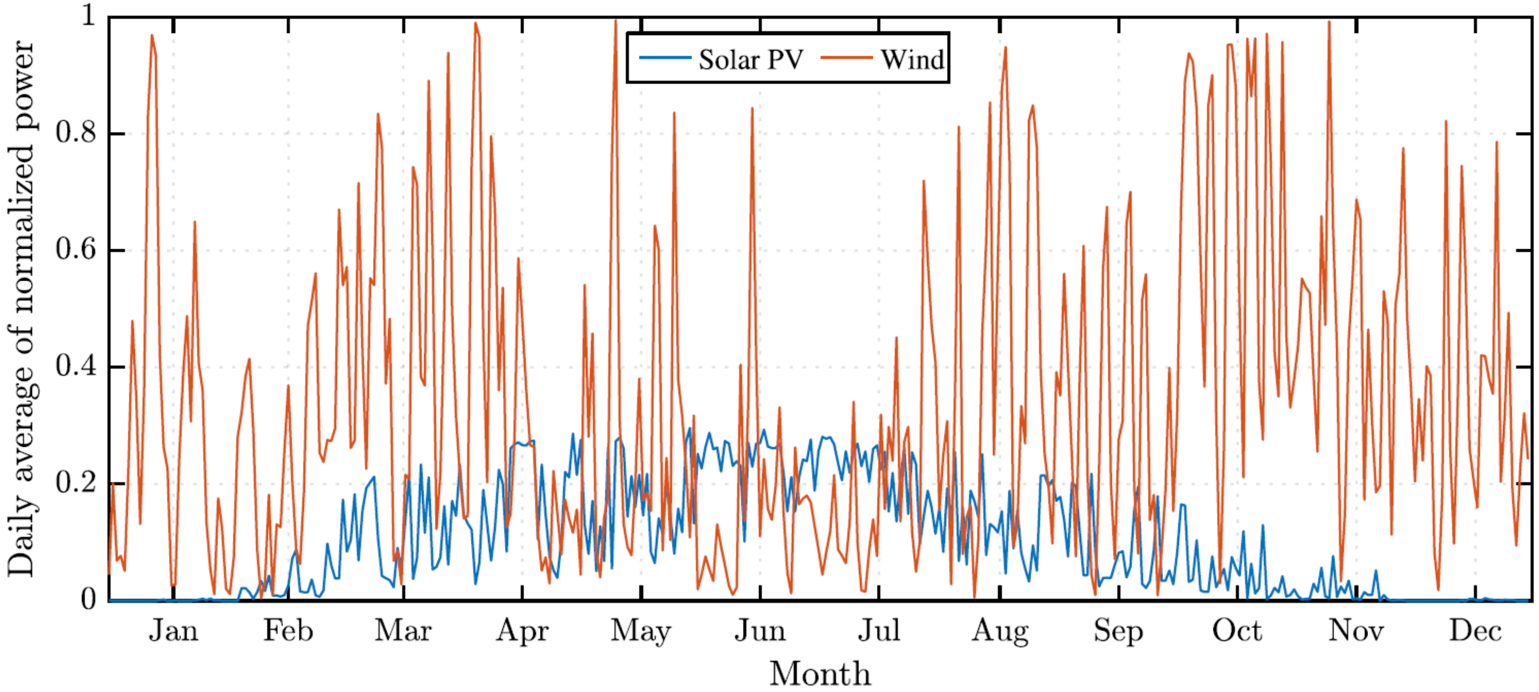


Fig. Daily average power values of the normalized solar PV and wind power time series.

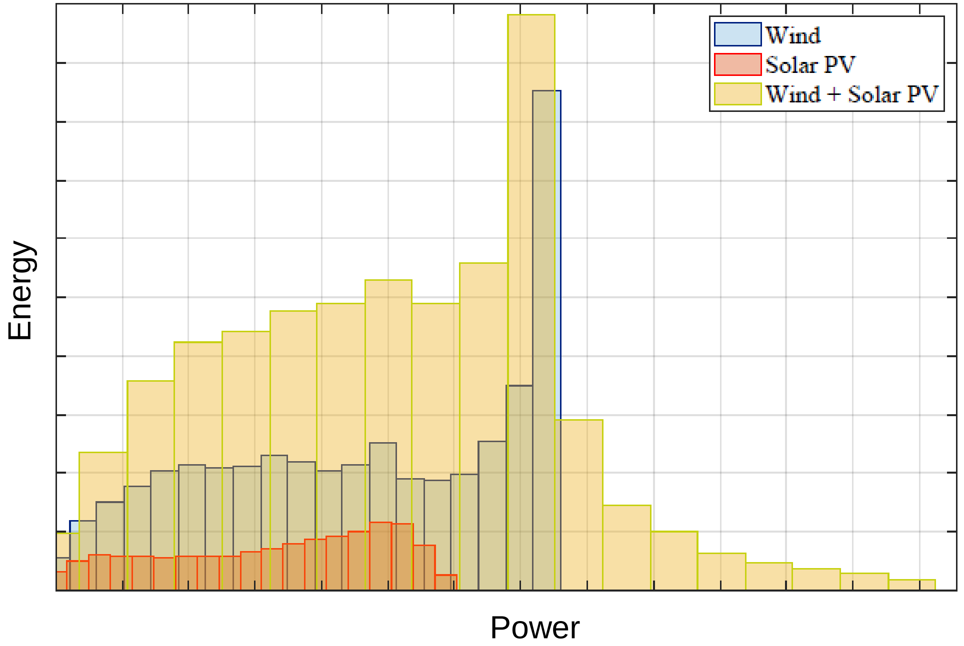


Fig. Energy and power production distribution of wind and solar power.

System optimization

- Simultaneous optimization of system control and component capacities
  - 11 Variables
    - $x_1, \dots, x_8$ → related to system control
    - x_9 → Solar PV peak power
    - x_{10} → Battery capacity
    - x_{11} → Nominal Wind power
  - 30-years lifetime plant simulation – 5 min time resolution
  - Technical models → Energy management, degradation, replacements and H_2 production:

    $$m_{\mathrm{H_2}}(x_1, \dots, x_{11})\ (\mathrm{kg\ H_2})$$
  - Economic models → CAPEX & OPEX, Discount rate and Learning curve → Levelized Cost Of Hydrogen (LCOH in €/kg)

Results – Different installation years

- Based on learning curves, plant optimization in 2020, 2022, 2030, 2035, 2040

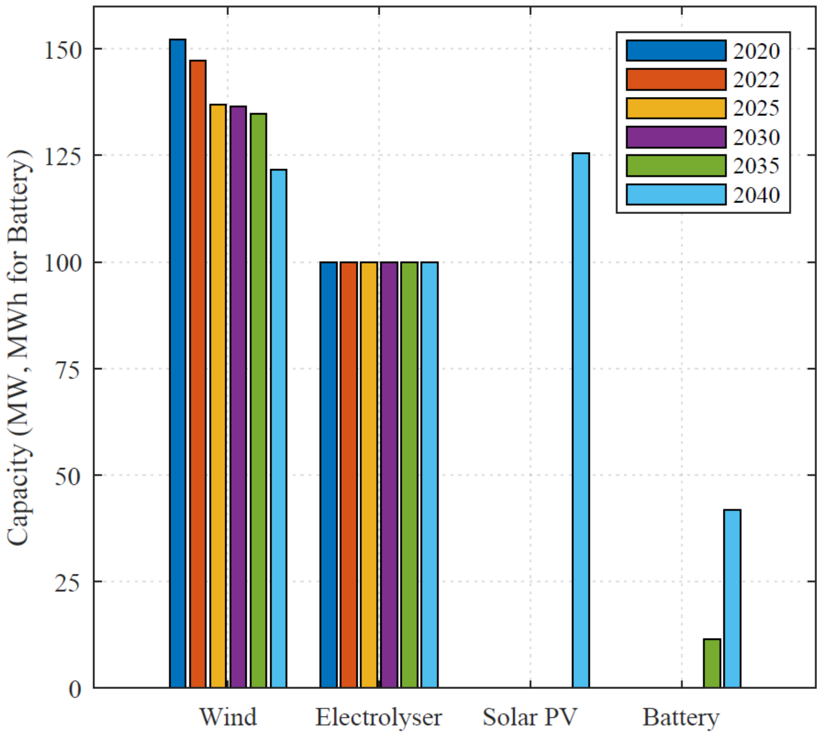


Fig. Optimal capacities: solar PV not included until 2040.

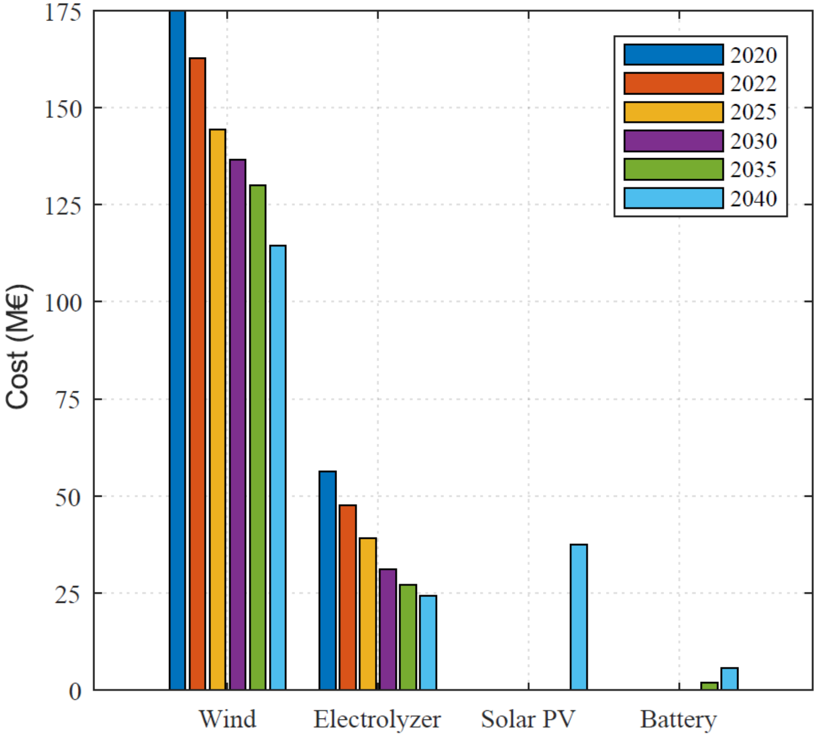
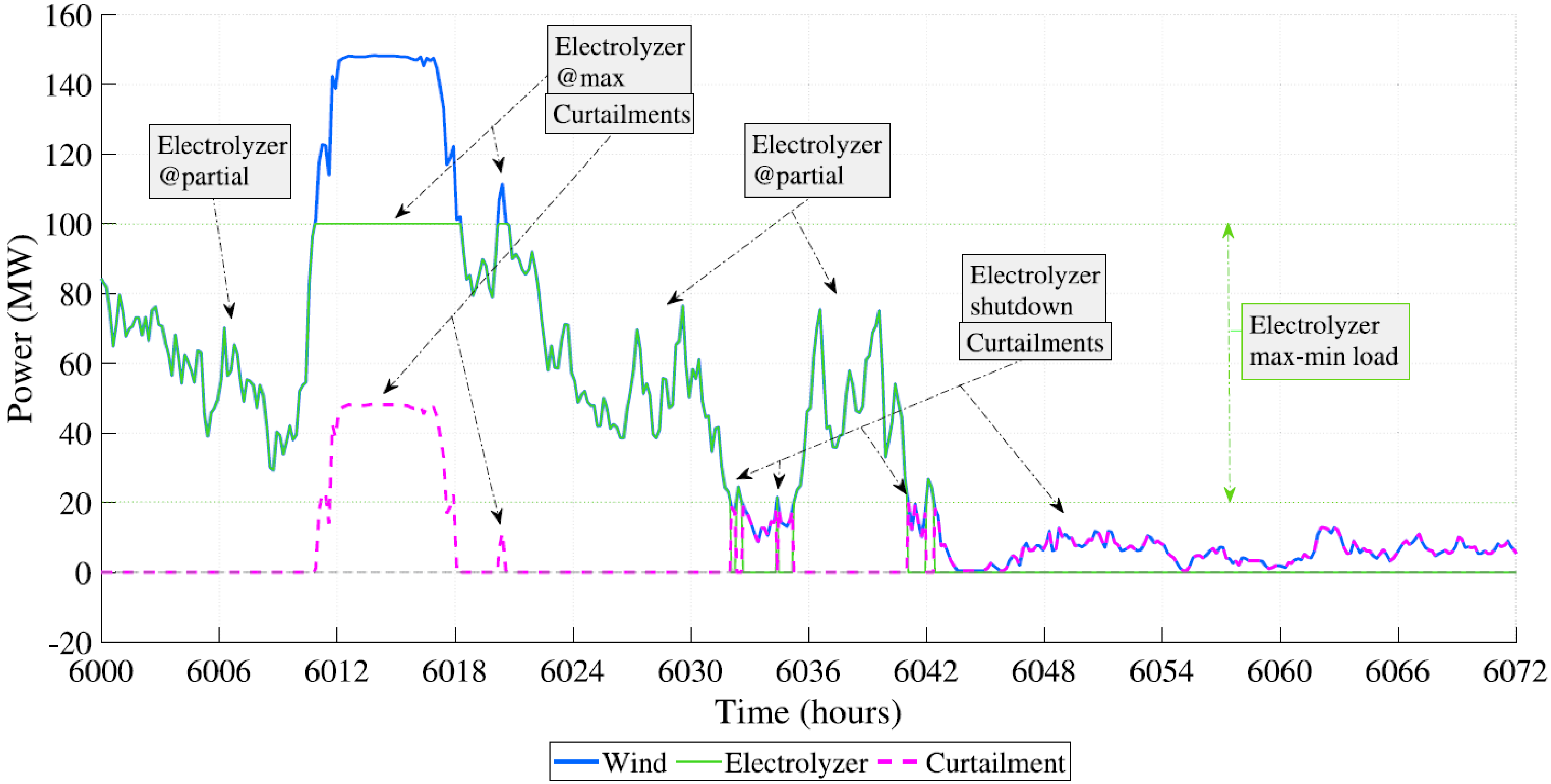


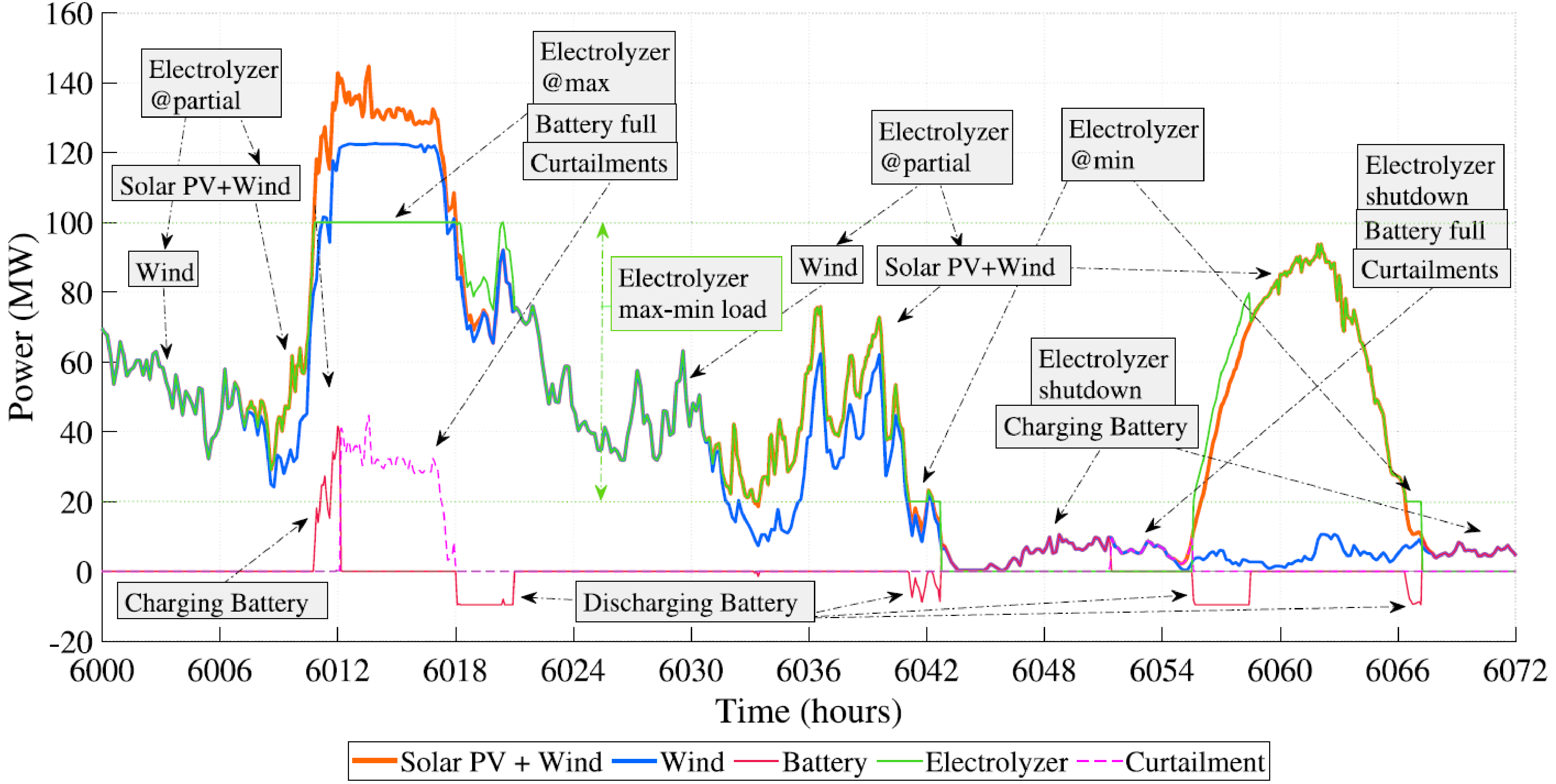
Fig. Initial costs.

⇒ The capacity factor of solar power is not enough to produce cheap hydrogen, so it cannot be used alone, like wind power.

Control – 2022 plant configuration



Control – 2040 plant configuration



Results

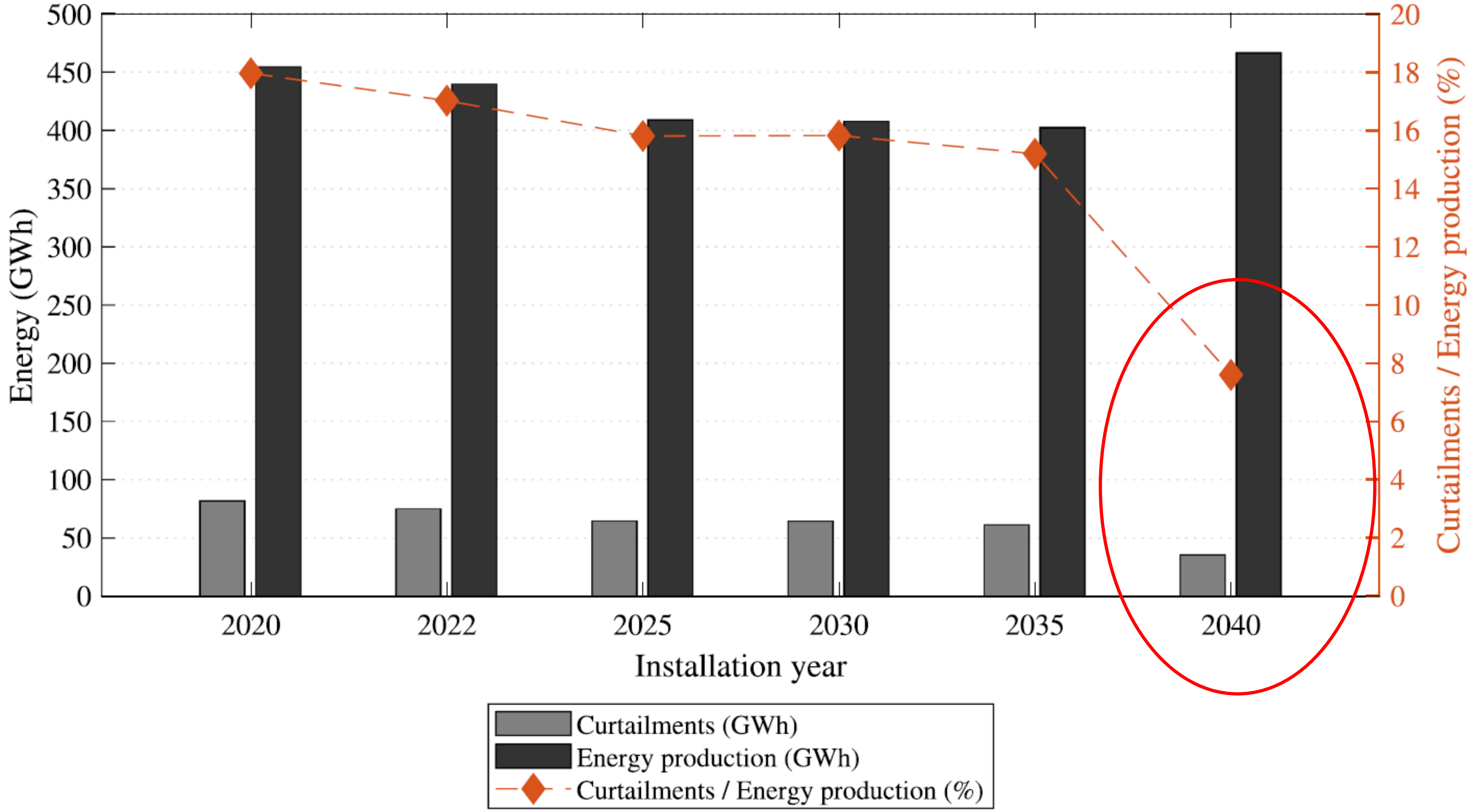


Fig. Annual energy production from the solar and wind power, and annual curtailments for each installation year simulated. The values are calculated as the annual average of the 30-year plant simulation.

Results

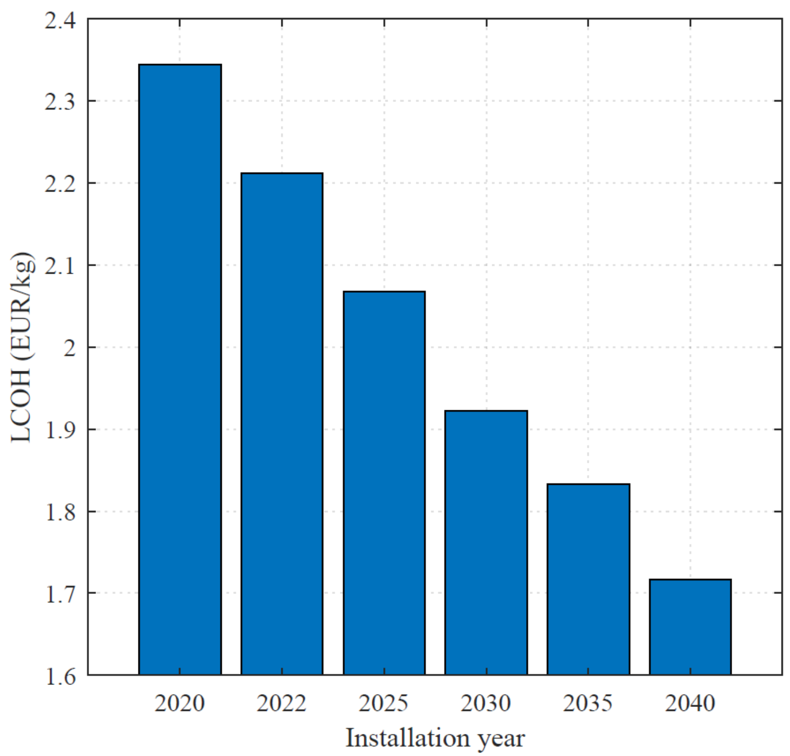


Fig. Levelized Cost Of Hydrogen (LCOH).

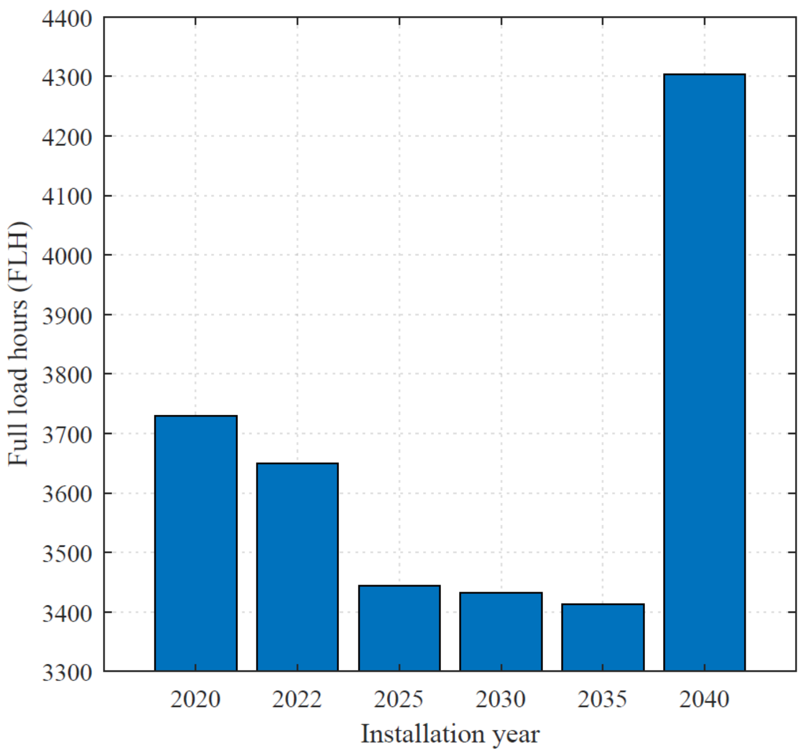
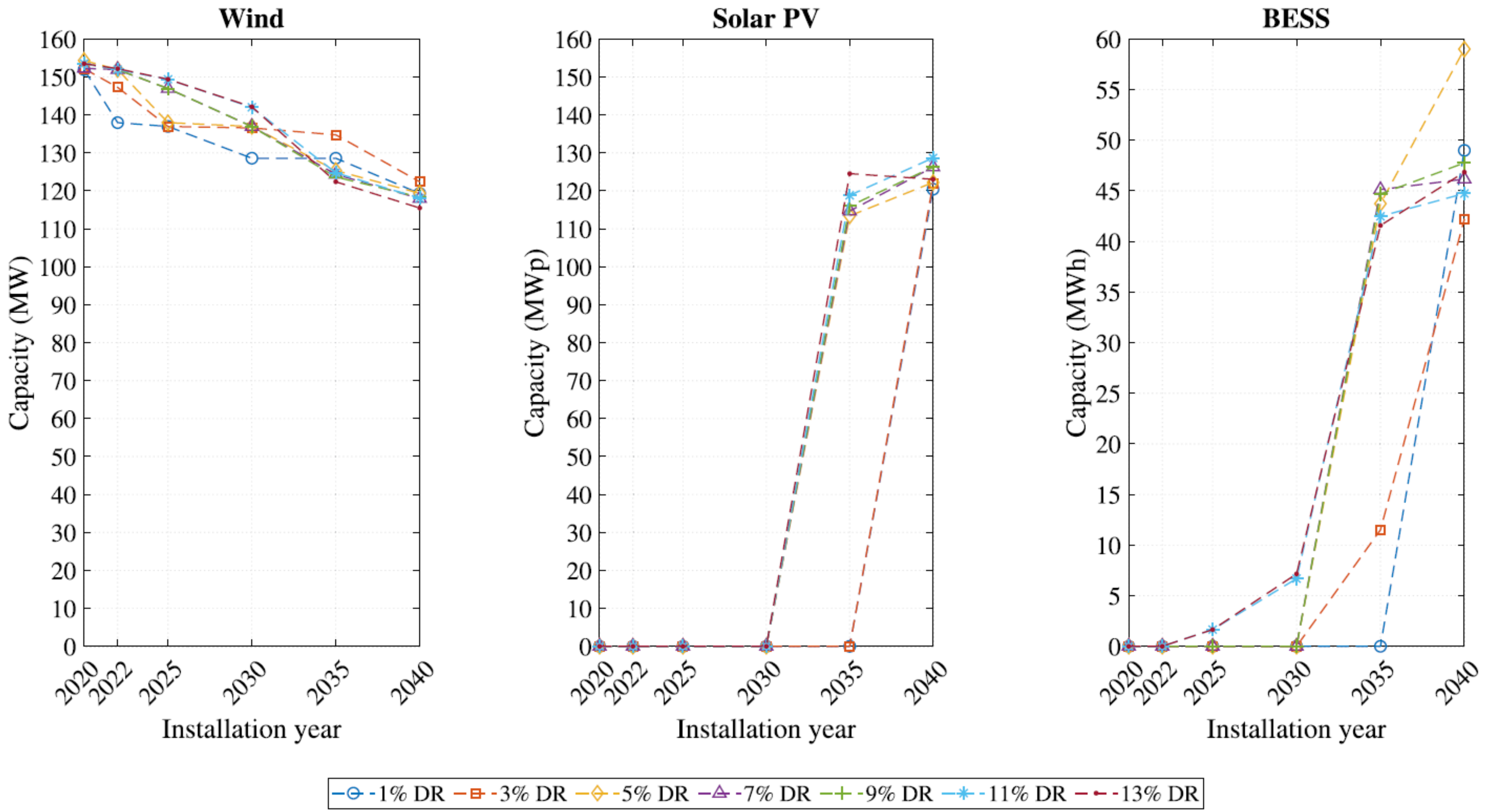


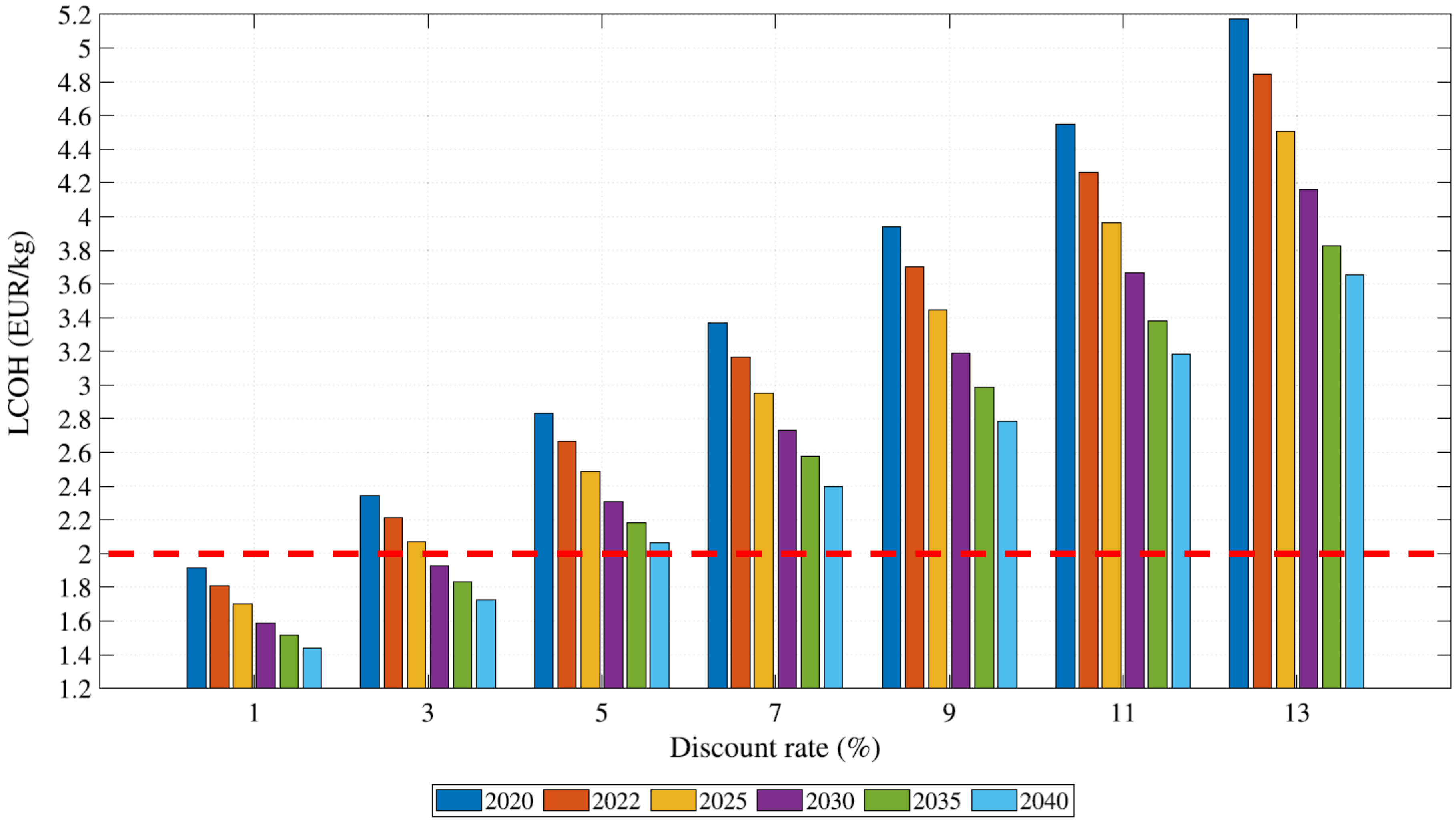
Fig. Electrolyzer full load hours.

⇒ Solar power increases full load hours of electrolyzers. It can be an important solution to reduce the need for storage capacity.

Results – Discount rate analysis



Results – Discount rate analysis



Learning curves

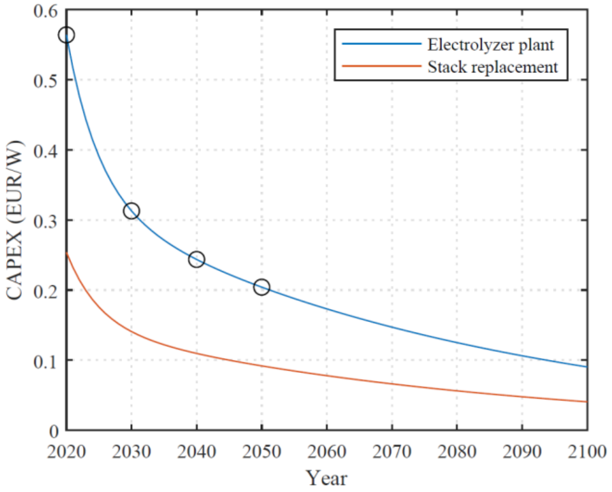


Fig. AWE.

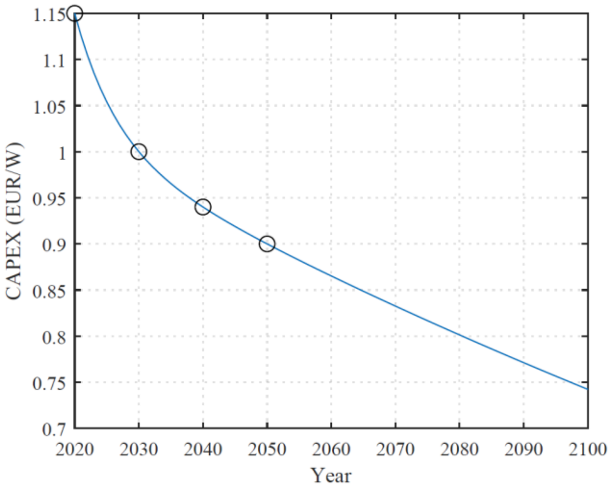


Fig. Wind.

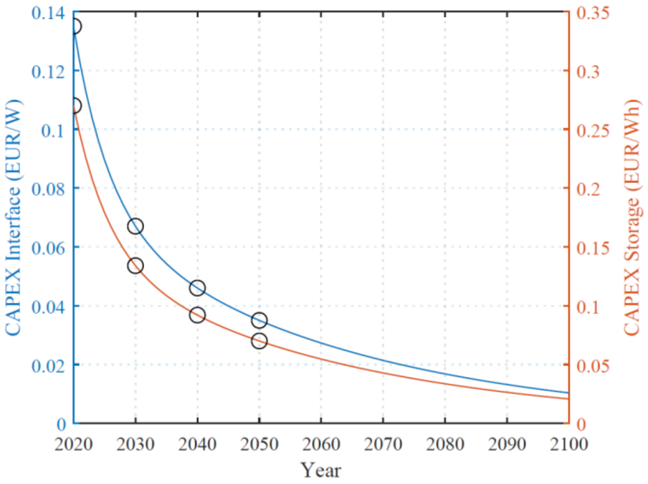


Fig. BESS.

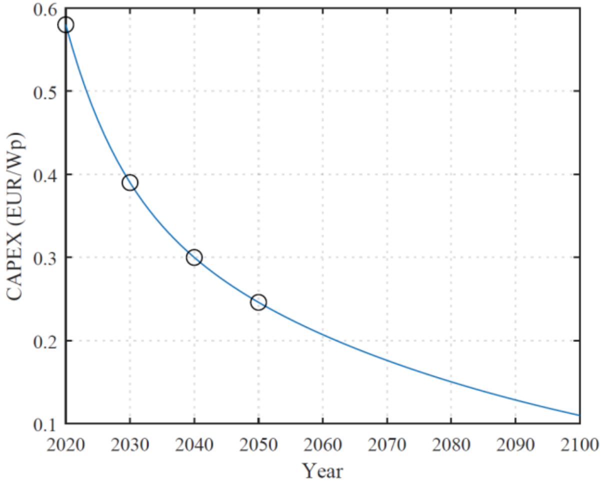


Fig. Solar PV.

Source for reference years 2020, 2030, 2040, 2050: M. Fasihi, C. Breyer, Baseload electricity and hydrogen supply based on hybrid PV-wind power plants, J. Cleaner Production 243 (2020), Article 118466, https://doi:10.1016/j.jclepro.2019.118466.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