Cost Optimal Design of Solar E-Methanol Production Powered by CSP/PV Hybrid Power Plants

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Introduction

- Due to the enormous potential of solar energy and the availability of unused land, the Earth's sunbelt could become a major producer and exporter of renewable energy in form of green hydrogen derivatives [1].
- Methanol, a versatile chemical building block, is one of the most promising hydrogen carriers [2]. When produced with green hydrogen and CO_2 from a sustainable source, methanol can be used to produce sustainable aviation fuel (SAF) through the Methanol-to-Jet fuel process [3].
- Even with very low investment costs for photovoltaic (PV) systems, it is challenging to produce hydrogen and hydrogen derivatives such as e-methanol cost-efficiently using only solar energy, due to the intermittent availability of the energy source.
- Combining PV with concentrated solar power (CSP) and thermal energy storage (TES) seems to be a good way to meet these requirements at sites with high solar irradiation. Furthermore, this combination enables a quasi-continuous operation of the electrolyzer and the methanol production plant.

CSP/PV hybrid concept and optimization variables

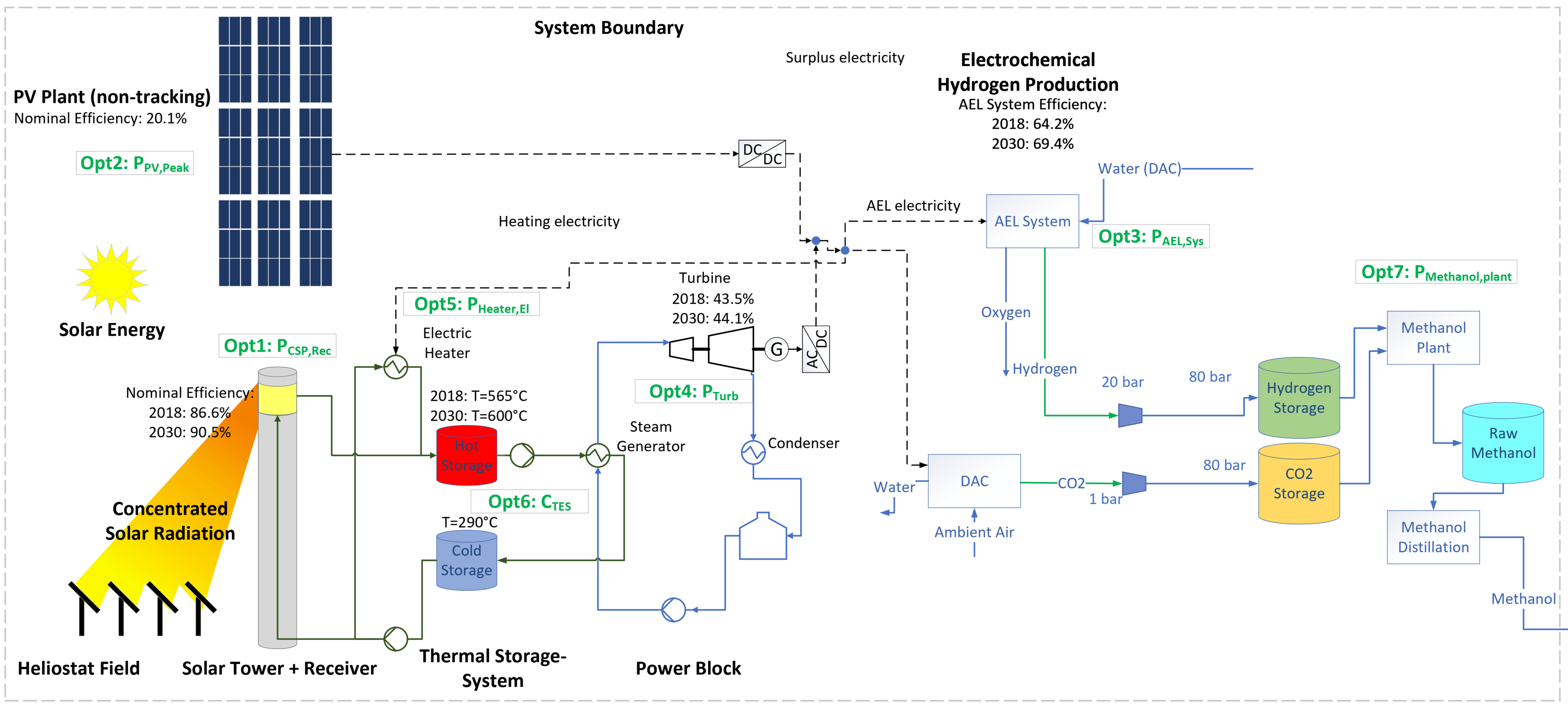

Fig. 1: Process scheme and optimization variables of the CSP/PV hybrid power plant for e-methanol production.

System design optimization

- Techno-economic model including operational strategy to use fluctuating electricity in a cascade [4].
- Global optimization with Pattern Search algorithm by MathWorks®
- Sizing of system components by minimization of product costs:

$$\min(\mathit{Levelized\ Cost\ of\ Methanol}) = f(P_{CSP,Rec}, P_{PV,Peak}, P_{AEL}, P_{Turb}, C_{TES}, P_{Heater,el}, P_{MeOH,plant})$$

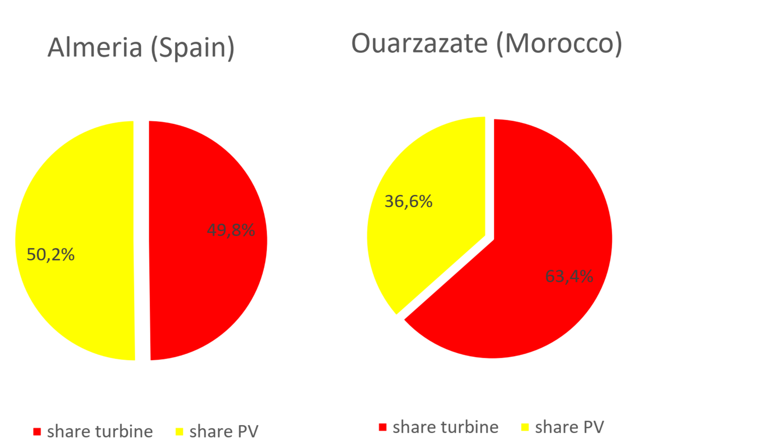

Fig. 2: Share of electricity provision at a regular and a good solar site.

Operational strategies

- Different operational modes and plant designs possible, depending on techno-economic boundary conditions.

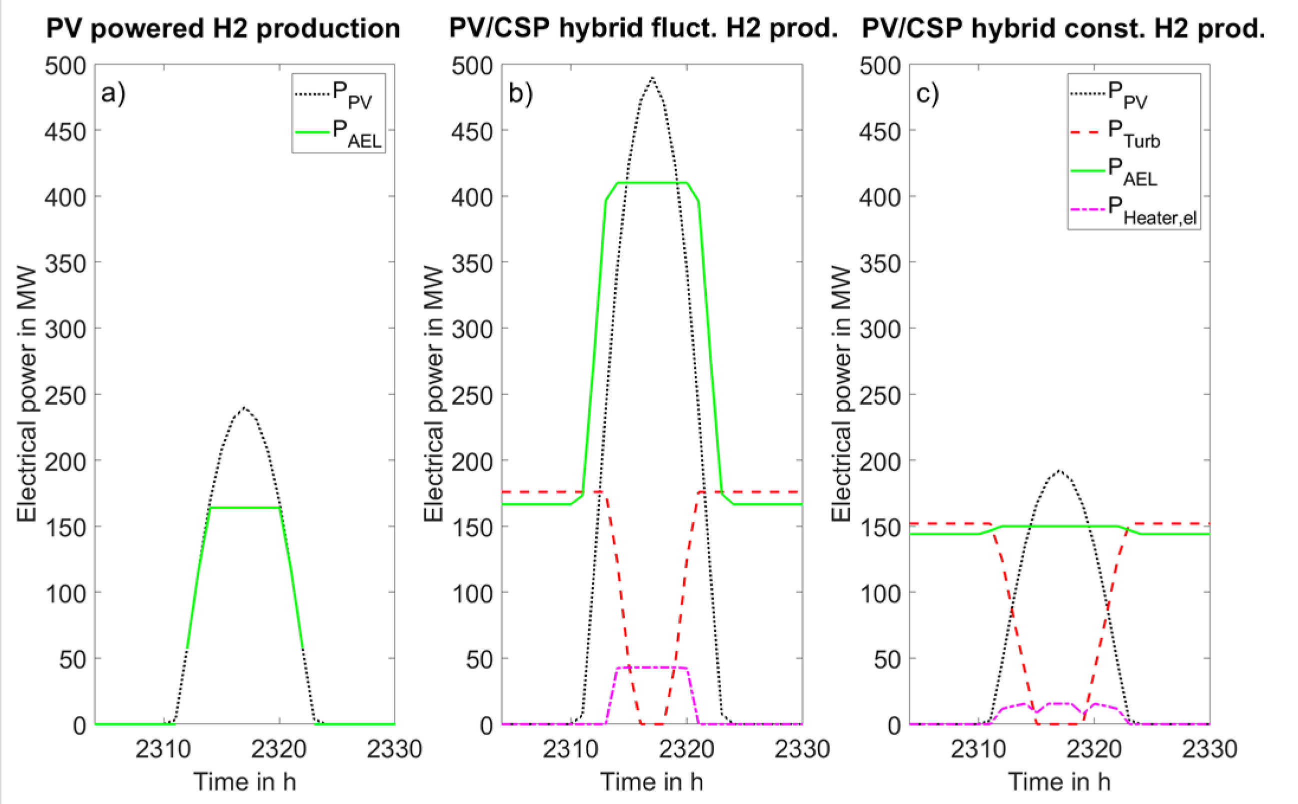

Fig. 3: Comparison of different solar electrolyzer operational concepts for a day with good solar irradiation [4]: a) only PV system, b) fluctuating CSP/PV system with high PV share, c) continuous CSP/PV system with high CSP share

Plant design

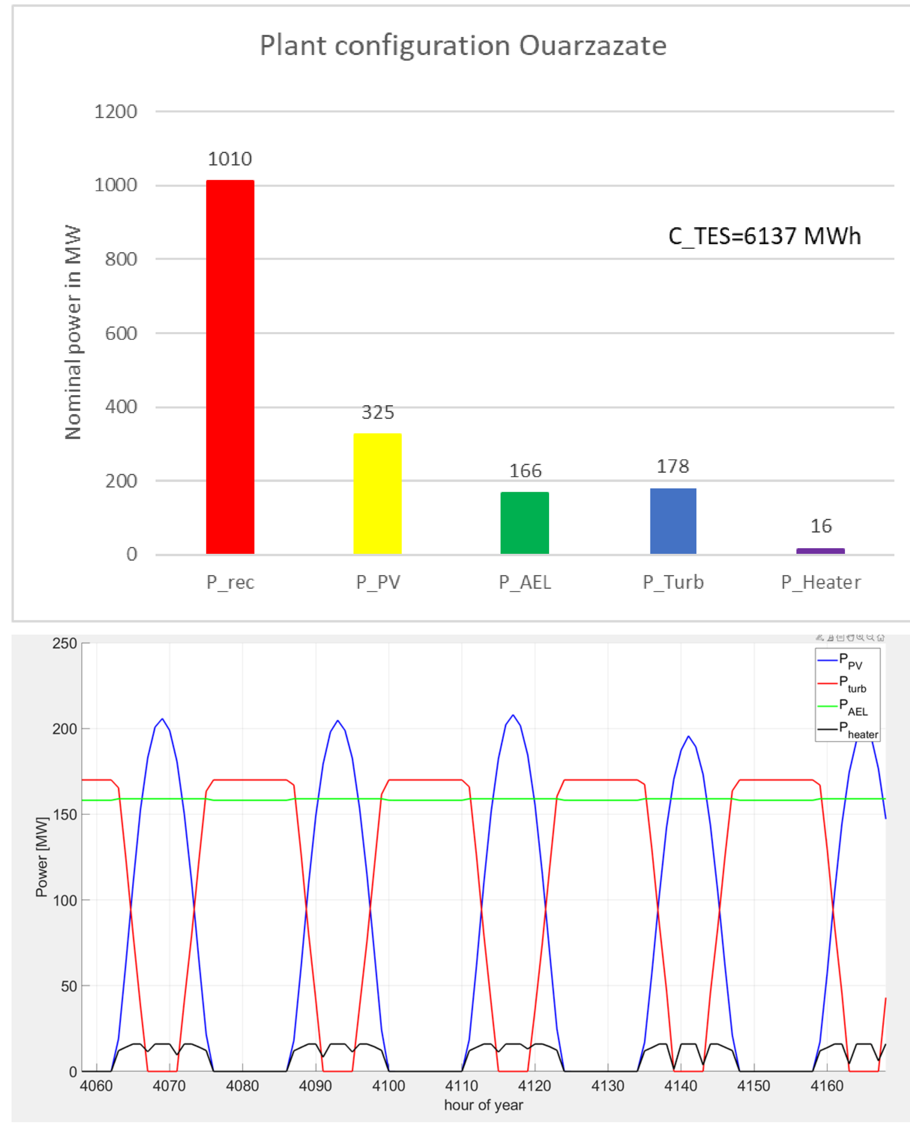

Fig. 4: Optimized plant design and operation at good solar site (Ouarzazate, Morocco).

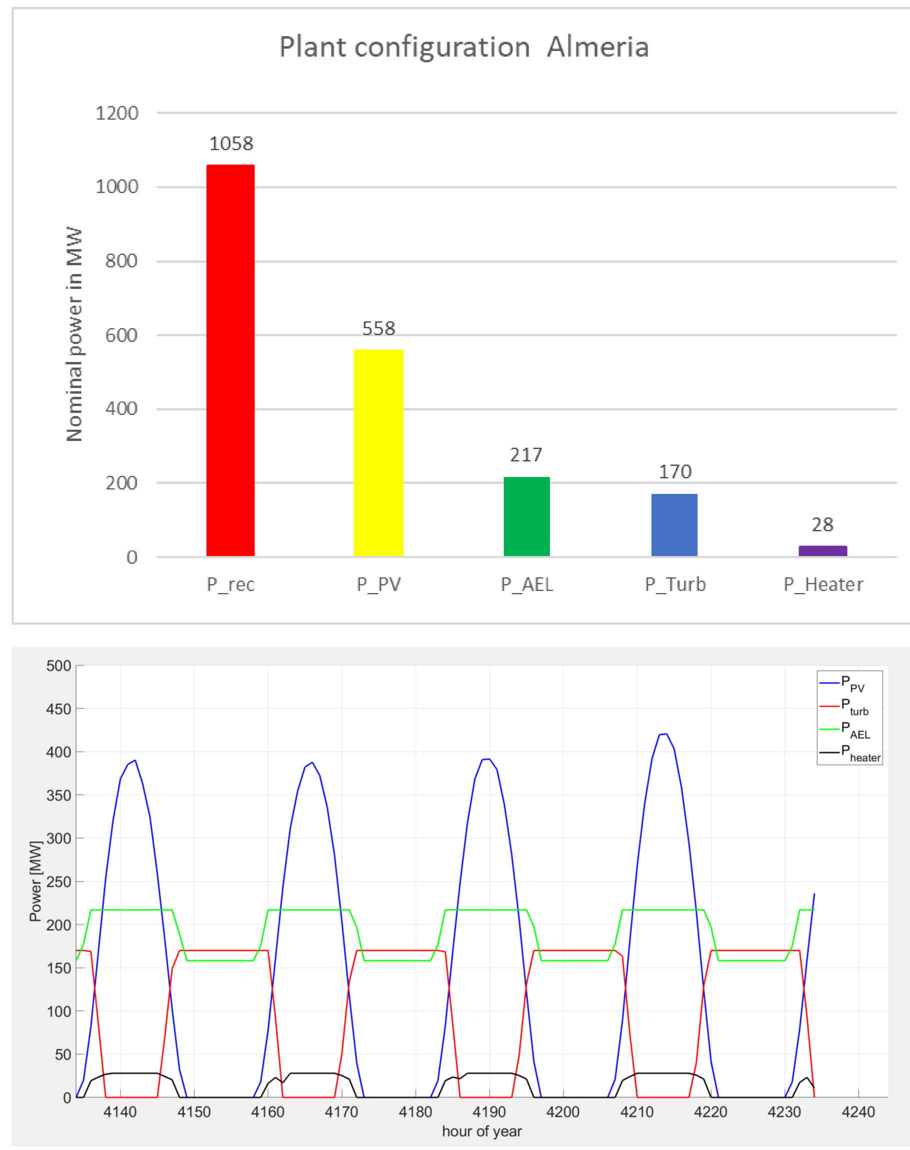

Fig. 5: Optimized plant design and operation at regular solar site (Almeria, Spain).

Summary and Outlook

- E-Methanol production based on CSP/PV hybrid power plants with thermal storage can achieve lower levelized product costs compared to only PV or only CSP systems.
- Combining solar-powered electrochemical hydrogen production with downstream processes, such as e-methanol production, favors continuous process designs. More than 8000 electrolyzer full load hours possible with this concept.
- At sites with higher direct irradiation (DNI), the share of turbine electricity production increases compared to regular CSP sites, approaching 2/3 of the total electricity supply.
- The concept of CSP hybridization can also be applied to other fluctuating renewable energy sources (e. g. wind energy), but the best compatibility generally being with PV (night/day operation).
- With a CO_2 price of 80 €/t, a Methanol price of 776 €/t is reached for Ouarzazate (2030).

References

[1] Roeb et al., https://elib.dlr.de/137796/ (2020)
[2] Plass et al., https://doi.org/10.1007/978-3-642-39709-7_8 (2014)
[3] Wormslev et al., http://dx.doi.org/10.6027/TN2016-538 (2016)
[4] Rosenstiel et al., Energies 2021,14, 3437, https://doi.org/10.3390/en14123437 (2021)

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