EuroSun 2026

Techno-economic optimization of hybrid CSP–PV systems with energy storage for continuous DME production

Summary

Dimethyl ether (DME) is an attractive low-carbon fuel and chemical intermediate due to its clean combustion and LPG-compatible logistics. We assess hybrid concentrating solar power (CSP) and photovoltaic (PV) supply with thermal and electrical storage for continuous CO_2-based DME production in northern Chile. We use a high-resolution process-coupled simulation and surrogate-assisted optimization to size generation, storage, and dispatch under a strict limit on purchased electricity. Results indicate that co-optimizing heat and power—especially CSP with thermal energy storage (TES) and an electric heater (EH) that converts otherwise-curtailed PV into useful process heat—enables continuous operation with reduced battery dependence compared to PV-only designs, while providing a pathway to a competitive levelized cost of DME.

Keywords: DME, hybrid CSP–PV, thermal energy storage, battery storage, electric heater

Field of application for the findings: Sustainable Energy Infrastructure and Electrification.

Addressed audience: Solar-thermal and PV system designers, Power-to-X developers, and techno-economic analysts.

1. Introduction

Electricity-based DME, produced from renewable hydrogen and captured CO_2, is increasingly discussed as (i) an LPG blendstock and transport fuel (including marine and heavy-duty use cases) and (ii) a versatile intermediate for chemicals. Compared to other synthetic liquids, DME benefits from established pressurized storage and transport infrastructure similar to that of LPG [2, 3].

A key challenge for DME plants is achieving a high capacity factor (electrical and thermal) despite variable renewable generation. Hybrid architectures that combine PV with CSP, which provides dispatchable electricity and high-temperature heat via TES, can offer additional flexibility, potentially reducing overall storage needs and lowering levelized fuel cost.

In this work, we summarize an integrated assessment of hybrid CSP–PV systems coupled to a 100 kton per year DME production chain. We compare four configurations: PV and battery energy storage (BESS) with either PEM or AEL electrolysis, and CSP–PV–BESS–EH with either proton-exchange membrane (PEM) or alkaline electrolysis (AEL). These configurations (250–400 MW_{el}) can self-sufficiently supply power and heat to the downstream processes with limited external electricity imports.

2. System and methods

Fig. 1 depicts the overall system. The hybrid plant supplies electricity and heat to a CO_2-based DME production chain comprising desalination, electrolysis, synthesis and purification, and intermediate H_2/MeOH buffers. DME is produced via a methanol intermediate, and the process requires a combination of electricity and heat, creating an opportunity for coupled heat–power optimization.

We consider two electrolyzer types: PEM and AEL, capturing the trade-off between operational flexibility and electrolyzer CAPEX/stack lifetime. We simulate the combined system in ColSim [4], a high-resolution solar-thermal simulation tool that we extend to represent hybrid renewable energy systems. The simulation framework uses a 10-minute time step over one year and techno-economic inputs are based on local cost data. We model the H_2–MeOH–DME chain as a set of black-box units. The hybrid CSP–PV plant modeling approach

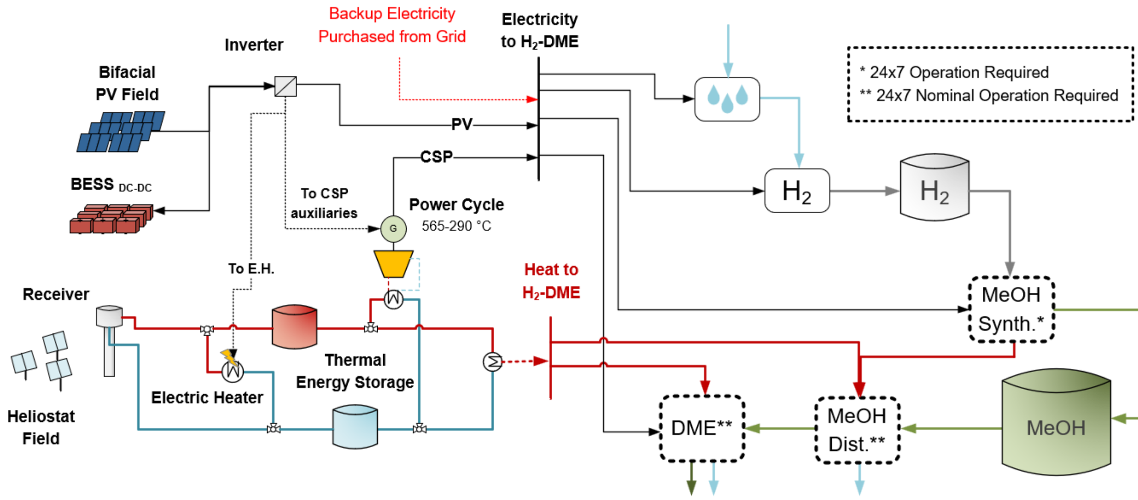

Fig. 1: Schematic of the hybrid CSP–PV configurations with electric-heater (EH) and battery energy storage system (BESS) integration that meet the electrical and thermal demands of the H_2–DME process.

follows previous high-resolution optimization studies for CSP–PV hybrids [1]. Optimization variables include PV capacity, CSP solar-field size (optical multiple), receiver and power-block sizing, TES capacity, BESS capacity, EH capacity, electrolyzer and MeOH synthesis capacities, and buffer/storage sizes. Dispatch controls prioritize continuous process operation while minimizing curtailment and purchased electricity.

To explore the design space efficiently, we use a surrogate-assisted optimization workflow. We first generate an initial design set using Latin hypercube sampling. We then train a random-forest surrogate to emulate simulation outputs. Finally, we apply a genetic algorithm to search for designs that minimize the levelized cost of DME (LCODME) subject to a purchased-electricity constraint of $C_{\text{pur}} \leq 10\%$. Key performance indicators (KPIs) include LCODME, curtailment, component utilization, and CAPEX/OPEX contributions.

3. Results and discussion

Across a large candidate set of techno-economic designs, all four configurations operate reliably under the grid-purchase constraint and achieve LCODME values less than 2.0 €/kg. All configurations consistently keep curtailment below 2%. Fig. 2 shows distributions of key design parameters and annual electrolyzer and MeOH synthesis utilization rates (U_{H2} and U_{MeOH}), illustrating the convergence of component sizing for each configuration. CSP–PV configurations achieve higher flexibility through electrical storage, thermal storage, and heat integration. In contrast, PV-only configurations rely more strongly on batteries and material buffers (e.g., H_2 storage) to maintain continuous operation. As a result, the LCODME for optimized CSP–PV configurations is 9–11% lower than PV configurations.

Three robust trends emerge:

- **TES-backed dispatchability improves electrolyzer utilization.** Optimal CSP–PV hybrid candidates achieve electrolyzer utilization rates greater than 70%, whereas PV–BESS configurations remain below 70%. One key reason for the high electrolyzer utilization is the nighttime dispatchability of CSP–PV configurations, which allows smaller electrolyzer capacities because units can be operated more frequently.
- **Electric-heater coupling improves renewable utilization.** High utilization of the EH (20–30%) not only mitigates curtailment by converting otherwise-curtailed PV electricity into useful heat but also contributes directly to delivering process heat.
- **Electrolyzer flexibility versus cost assumptions.** PEM designs can operate between 0–100% load, while AEL designs require continuous 24/7 operation at a minimum load of 20%. The flexibility of the PEM electrolyzer, however, does not justify its higher cost. AEL configurations achieve 10–14%

lower LCODME than PEM configurations when paired with adequate storage and dispatchable supply (TES/CSP), reflecting lower electrolyzer cost assumptions.

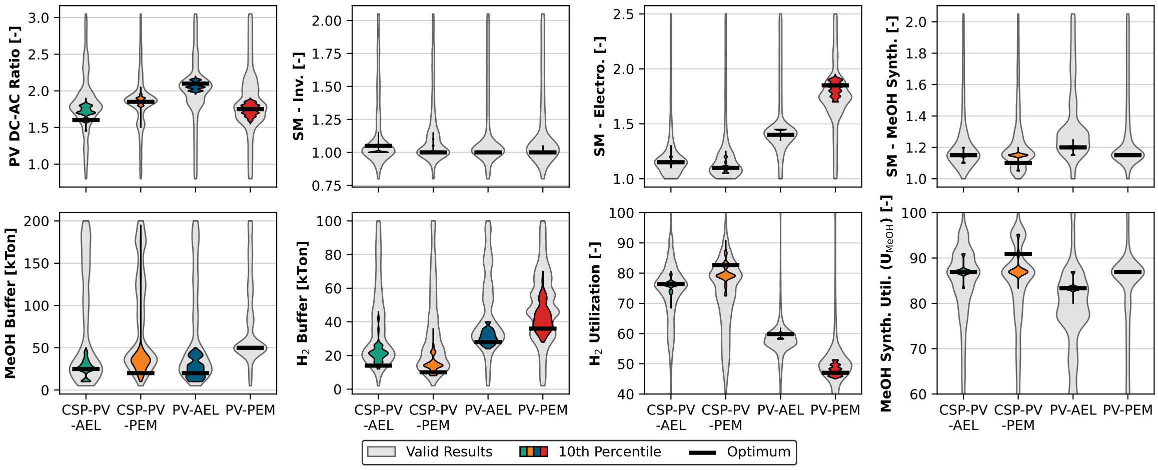

Fig. 2: KPI distributions by configuration shown as violin plots. Gray: all valid candidates (within the constraint $C_{pur} \leq 10\%$); colored: top 10th percentile by LCODME; black bar: best valid LCODME.

A cost breakdown indicates that renewable energy subsystems dominate installed cost, with the electrolyzer as the second-largest contributor. Consequently, LCODME is most sensitive to (i) PV and CSP investment costs, (ii) electrolyzer CAPEX and (iii) CO_2 sourcing. Improving round-trip efficiencies (TES, power block, and battery) and reducing curtailment via coupled heat use provide additional leverage.

4. Conclusions

Hybrid CSP–PV systems that co-optimize electricity and process heat can materially improve operability and reduce the main cost drivers of continuous DME production in high-solar-resource regions. The combination of TES-backed dispatchability and an electric heater to utilize surplus PV reduces curtailment and battery requirements, enabling designs that satisfy strict limits on purchased electricity while maintaining high plant utilization. Future work should incorporate degradation-aware electrolyzer and synthesis-loop models, compare direct and indirect (methanol-mediated) DME synthesis routes explicitly, and extend the framework to multi-product PtX hubs.

5. Acknowledgments

The projects, under which the work presented in this paper has been conducted, was funded by the German Federal Ministry for Research, Technology and Space (BMFS, code 03SF0615A). The authors of this publication are responsible for its contents.

References

[1] Chandler, N., Marshal, D., Klein, M., Heimsath, A., Wittwer, C., Platzer, W., Bern, G., 2026. Optimizing high-resolution CSP–PV hybrid power plant configurations for Morocco: A techno-economic study. *Solar Energy*, preprint.

[2] Florentinus, A., Hamelinck, C., 2012. Potential of biofuels for shipping. ECOFYS.

[3] Hsieh, C.-w.C., Felby, C., 2017. Biofuels for the marine shipping sector. IEA Bioenergy.

[4] Wittwer, C., 1999. ColSim – Simulation von Regelungssystemen in aktiven solarthermischen Anlagen. PhD thesis, Karlsruhe Institut für Technologie.