Parametric Optimization Approaches of a 100 MW Plant with Multiple CSP and PV Hybridization Strategies

Fraunhofer ISE
universität freiburg
Center for Renewable Energy ZEE Albert-Ludwigs-Universität Freiburg

Nicholas Chandler[1,a)], Shahab Rohani[1], Gregor Bern[1]

[1] *Fraunhofer Institute for Solar Energy Systems ISE. Heidenhofstr. 2, 79110 Freiburg, Germany*

[a)] *Correspondent author, email: nicholas.chandler@ise.fraunhofer.de*

In the research and development of concentrating solar power (CSP), the potential of hybridization with variable renewable energy technologies provides a unique solution to reduce the overall costs of the system, while fully utilizing the benefits of a dispatchable operation which CSP can provide. The hybridization of CSP and Photovoltaics (PV) is a common configuration solution proposed in research, however the composition and functionality of a CSP-PV hybrid configuration can vary widely. One aim of this Ph.D. is to investigate multiple hybridization approaches that consist of several CSP and PV technology combinations, in order to identify the techno-economic advantages of each hybridization approach.

CSP + PV Hybridization

Hybridization can generally fall into two categories:

Co-Location: CSP and PV share the same infrastructure but operate independently in order to meet a demand.

Technology Integration: In addition to functionality of co-location, CSP and PV are integrated at the plant level. For example, an electric heater can be utilized to create a Power-to-Heat-to-Power (P2H2P) flow [1] between the CSP and PV portions of the plant (**Figure 2**, center of poster).

Optimization with ColSimCSP

Fraunhofer ISE's inhouse, transient thermal power plant simulation tool, ColSimCSP [2], was used to simulate and determine the annual generation for each configuration. Each simulation produces high-resolution data (120s) which provide insight into component interdependencies that show the technology "behavior and interaction" for every time-step. An advanced feature of ColSimCSP is its ability to execute complex parameterization studies (**Figure 2**) which produce 1000's of unique simulation results. From these results, the configuration with the lowest Levelized Cost of Electricity (LCOE) within a Capacity Factor (CF) range is considered as the techno-economic optimum

Importance of Solar Resource

The two locations considered (**Table 1**) demonstrate the impact solar resource can have on the performance of a hybrid system (**Figure 1**). Three critical observations should be made when considering a location and its solar resource:

- DNI is the predominant factor for CSP performance
- PV performance is more dependent on the GHI than DNI
- Therefore, meteorological conditions have significant influence on the Hybridization technology composition!

Table 1: Solar resource breakdown for each location considered in this work

	DHI	DNI	GHI	unit
Antofagasta, CL	630.7	2518.8	2254.5	kWh/m²/yr.
Dubai, UAE	835.6	1757.8	1999.3	kWh/m²/yr.

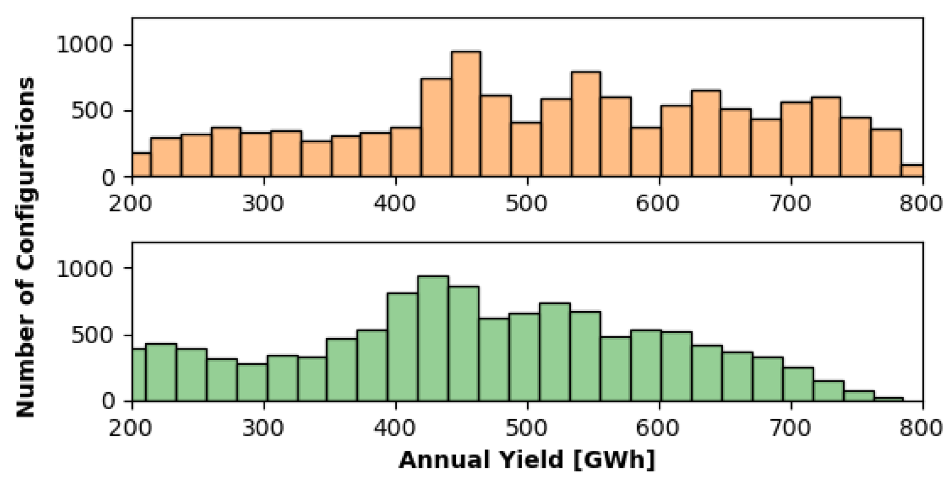
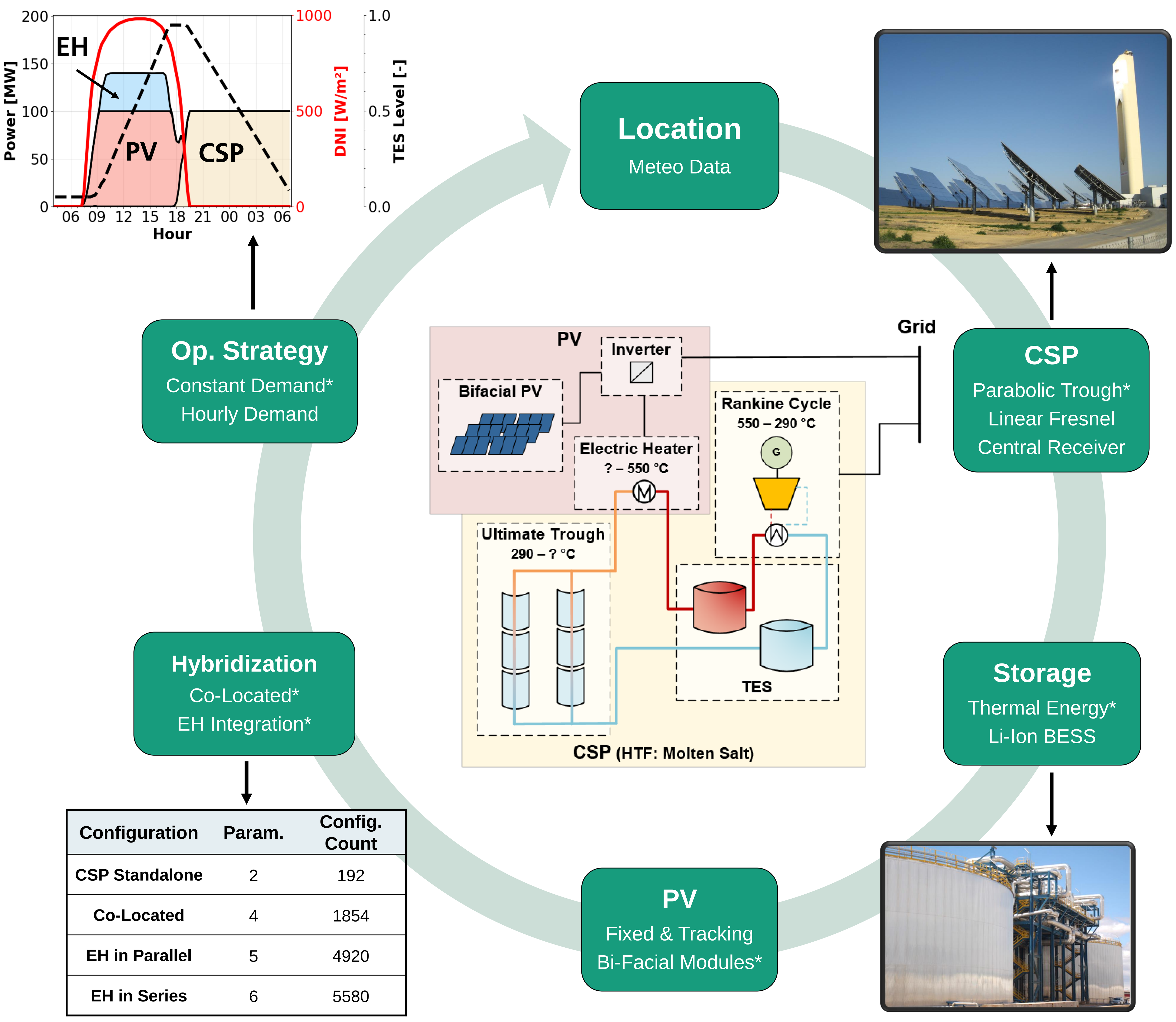


Figure 1: Distribution of the annual yield from simulation results (+12 000) for two locations: Antofagasta, Chile (top, orange) and Dubai, UAE (bottom, green).



Configuration	Param.	Config. Count
CSP Standalone	2	192
Co-Located	4	1854
EH in Parallel	5	4920
EH in Series	6	5580

Figure 2: This cycle depicts the ColSimCSP optimization process and each box shows the different components that can be parameterized. (indicates which components were considered for this work.) **[Center]** Diagram of a CSP+PV Hybrid configuration with an electric heater in series. **[Top Left]** A constant demand power dispatch strategy for a configuration with an electric heater. **[Top Right]** Photo of a solar tower which could also be considered in a hybridized configuration. **[Bottom Left]** A table depicting the different configurations considered for this work. For each location, the number of parameters considered and the total number of simulations performed per configuration are stated. **[Bottom Right]** Exemplary image of a solar thermal storage tank (molten salt) [3]*

Different Optimizations for Different Scenarios

- Five configurations which meet a 100 MW_e demand
- High CSP Price or Moderate CSP Price
- Moderate PV price

For a high DNI location (Antofagasta) (**Figure 3**), the following optimization trends can be observed:

- Low CF requirements favor standalone PV
- Mid CF requirements favor co-located configurations
- High CF requirements favor E.H. configurations

In a high solar resource environment with less adequate DNI, (Dubai), the optimization results are shown in greater detail. By considering a smaller optimization CF step (0.5 from 5) and neighboring results (± 0.5 c$/kWh) in **Figure 4**, the optimization sensitivity is clearly seen. Which factors can thus impact the optimization sensitivity?

- A minor modification in component performance
- Small changes in the pricing assumptions
- Location meteorological and economic conditions
- Resolution of parameterization steps

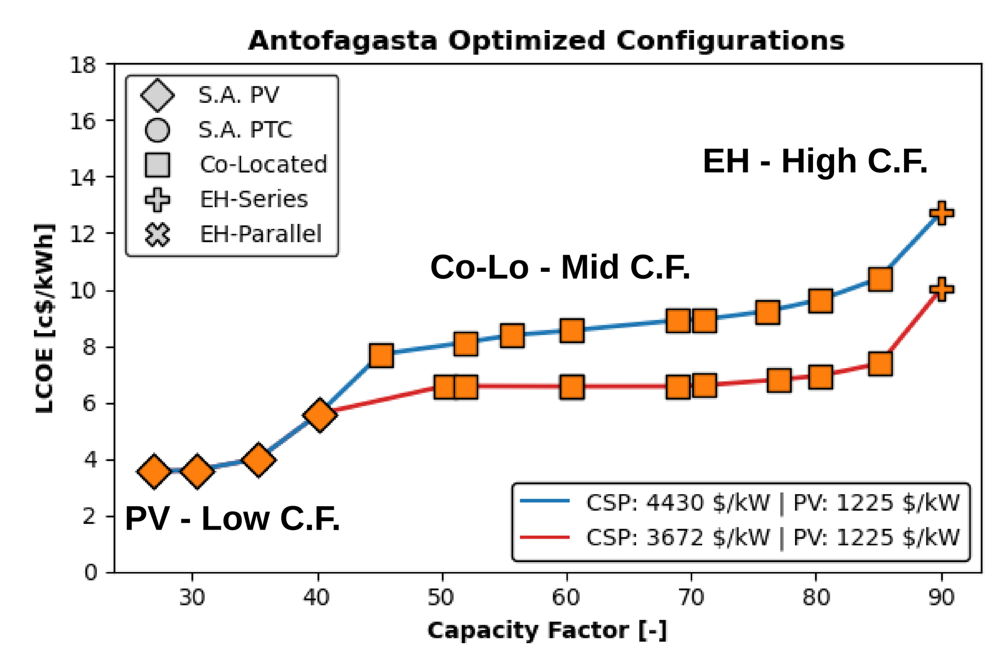


Figure 3: Each marker represents the optimized configuration per CF range. The blue line indicates expensive CSP pricing scenario while the red line indicates moderate CSP pricing.

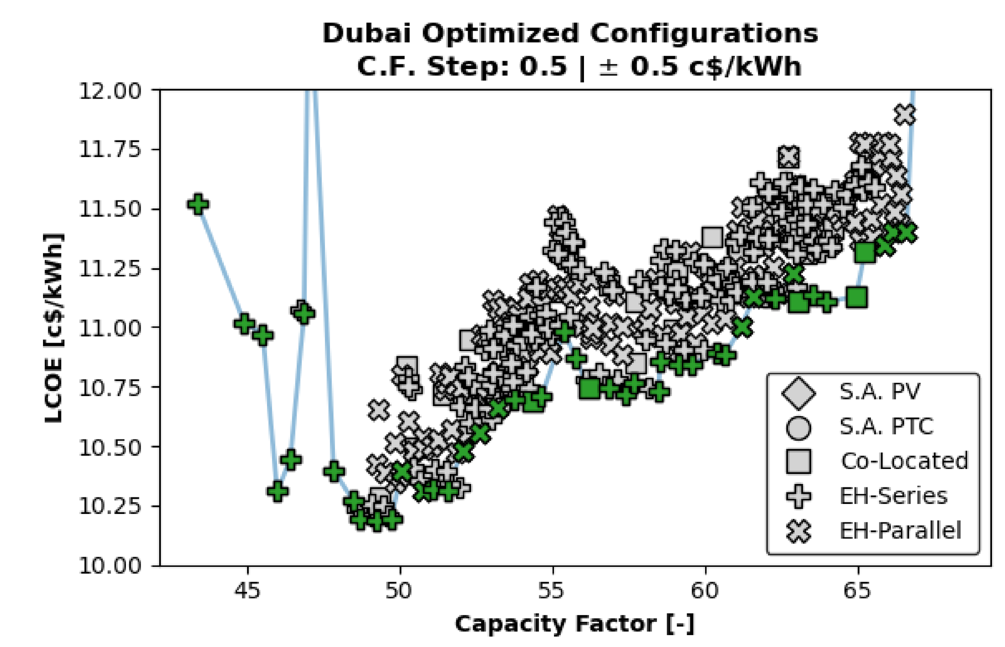


Figure 4: Optimization sensitivity of the Dubai study assuming an expensive CSP pricing scenario. Green colored markers represent the optimized configuration per CF step while the grey represent results within ± 0.5 c$/kWh of the optima LCOE.

[1] Giuliano, Stefano, Michael Puppe, and Kareem Noureldin. "Power-to-heat in CSP systems for capacity expansion." AIP Conference Proceedings. Vol. 2126. No. 1. AIP Publishing, 2019.
[2] Wittwer, Christof, et al. "ColSim-a new simulation environment for complex system analysis and controllers." Proc. of the 7-th IBPSA Conference. Vol. 1. 2001.
[3] Bauer, Thomas, Christian Odenthal, and Alexander Bonk. "Molten salt storage for power generation." Chemie Ingenieur Technik 93.4 (2021): 534-546.

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