SOLAR TOWER LCOE IN CHILE: COMPARATIVE STUDY

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40 YEARS
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Fraunhofer Institute for Solar Energy Systems ISE

Chile: Solar Thermal for Power and Heat

International Webinar, May 26, 2021

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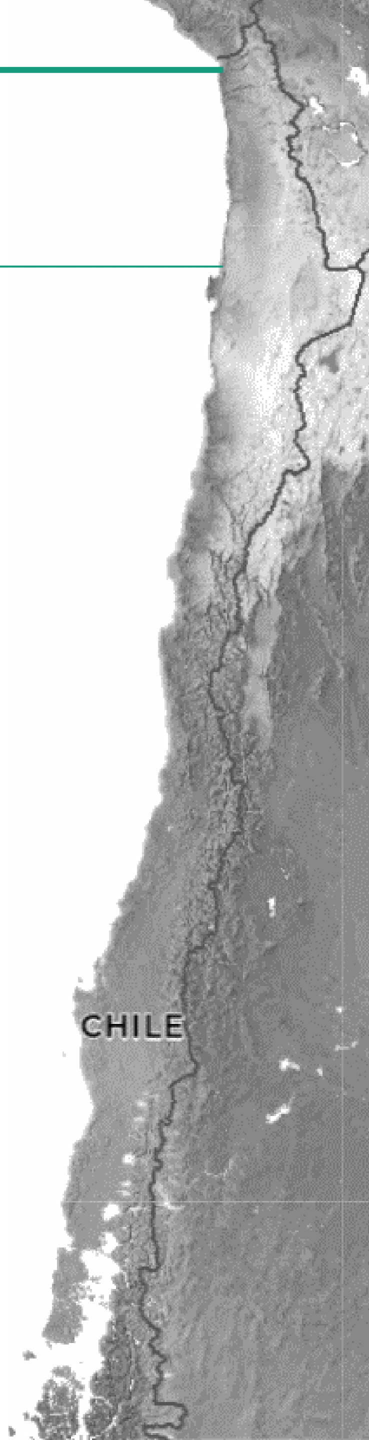
CONTENT

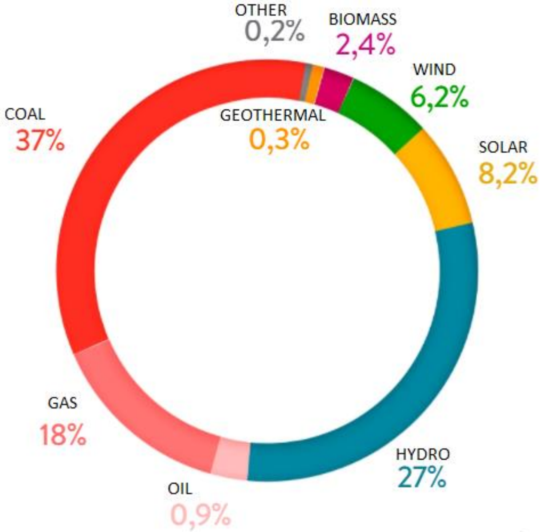


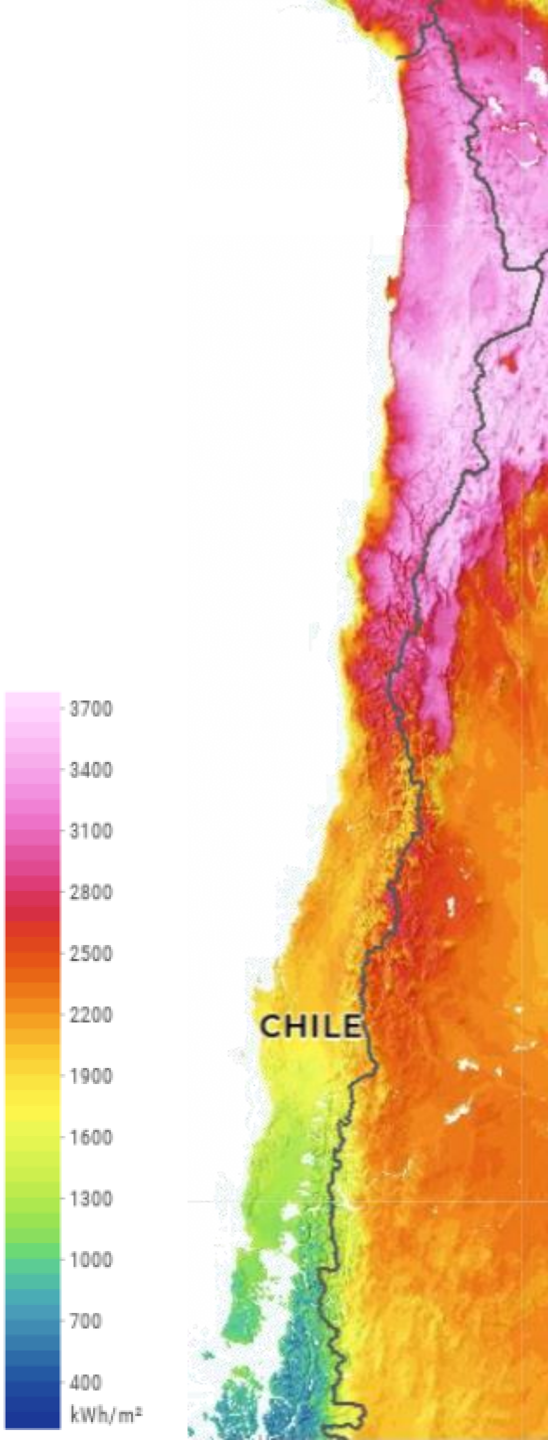
Introduction
Background and objective of the study

- Techno economic study to optimize LCOE of solar towers in Chile with varying storage capacity, solar multiple and heliostat field sizing factor.

- Chile presents a big potential for solar thermal technology due to high DNI values. [2]

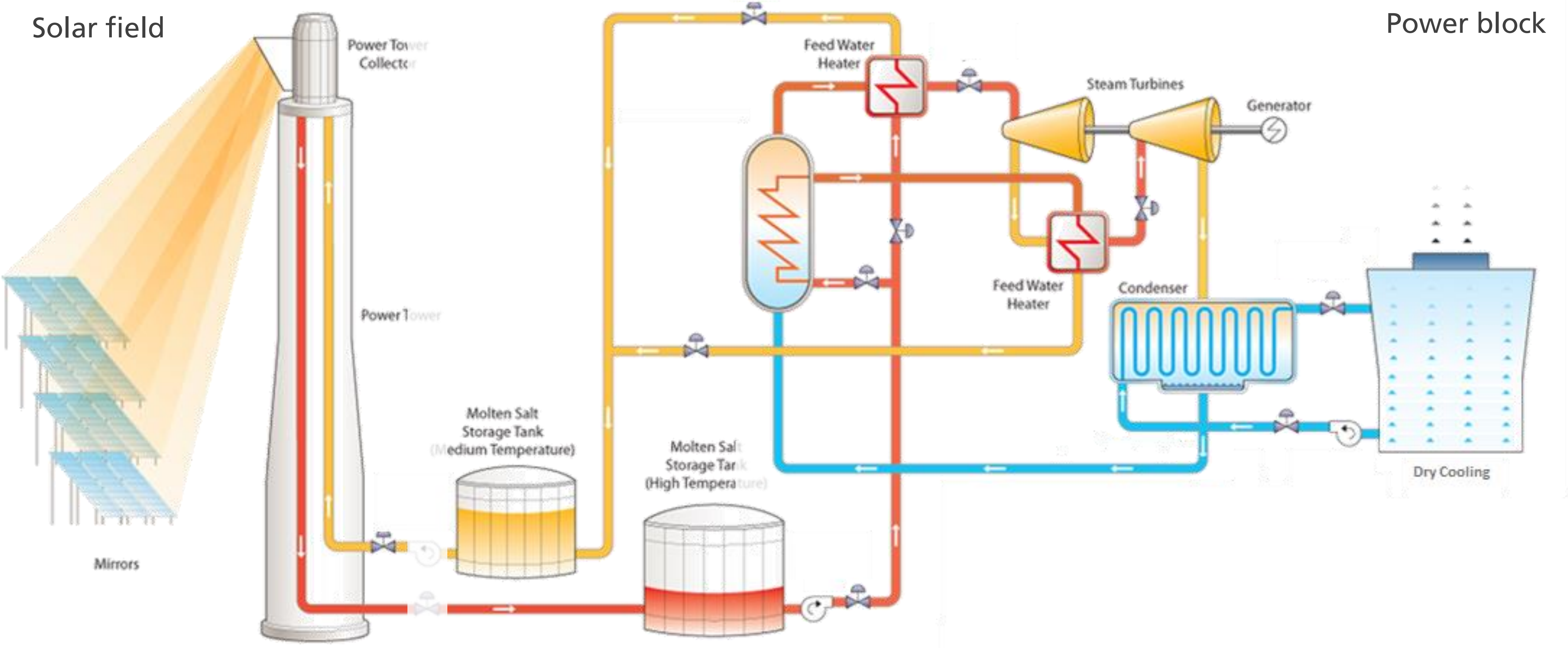
- Electricity generation in Chile is mostly based on imported fossil fuels (54%) and hydro power plants (27%). [3]





[2] Global Solar Atlas. https://globalsolaratlas.info/map
[3] Boletín del mercado eléctrico. Asociación de generadoras de chile. (2020).

Introduction
System description: solar tower plants



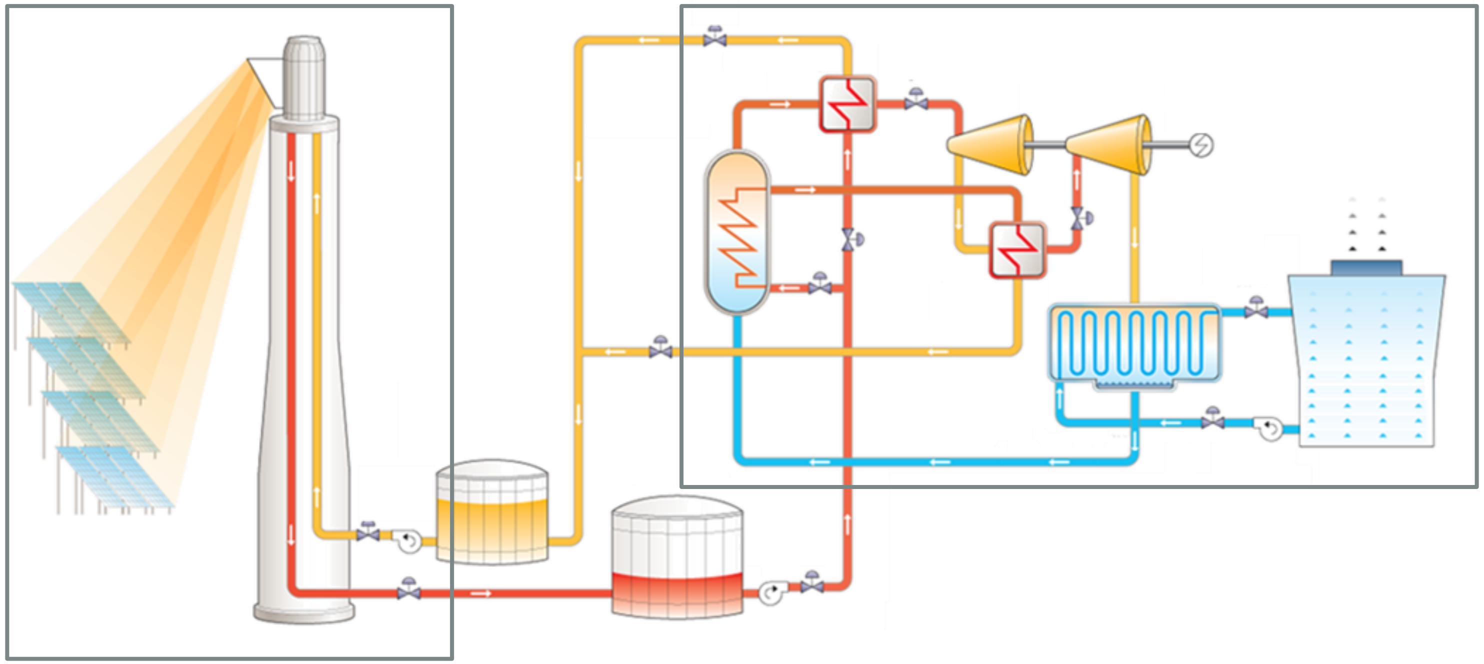
Thermal energy storage

[1] Image adapted from: Abbas, Mohamed. (2013). Parametric Study of the installation of a Solar Power Tower plant under Saharan Climate of Algeria: case study of Tamanrasset.

Introduction
Solar multiple

Ratio between the thermal power produced by the solar field at the design point and the thermal power required by the power block at nominal conditions.

$$SM = \left. \frac{\dot{Q}_{th,\,solar-field}}{\dot{Q}_{th,\,power-block}} \right|_{design\_point}$$



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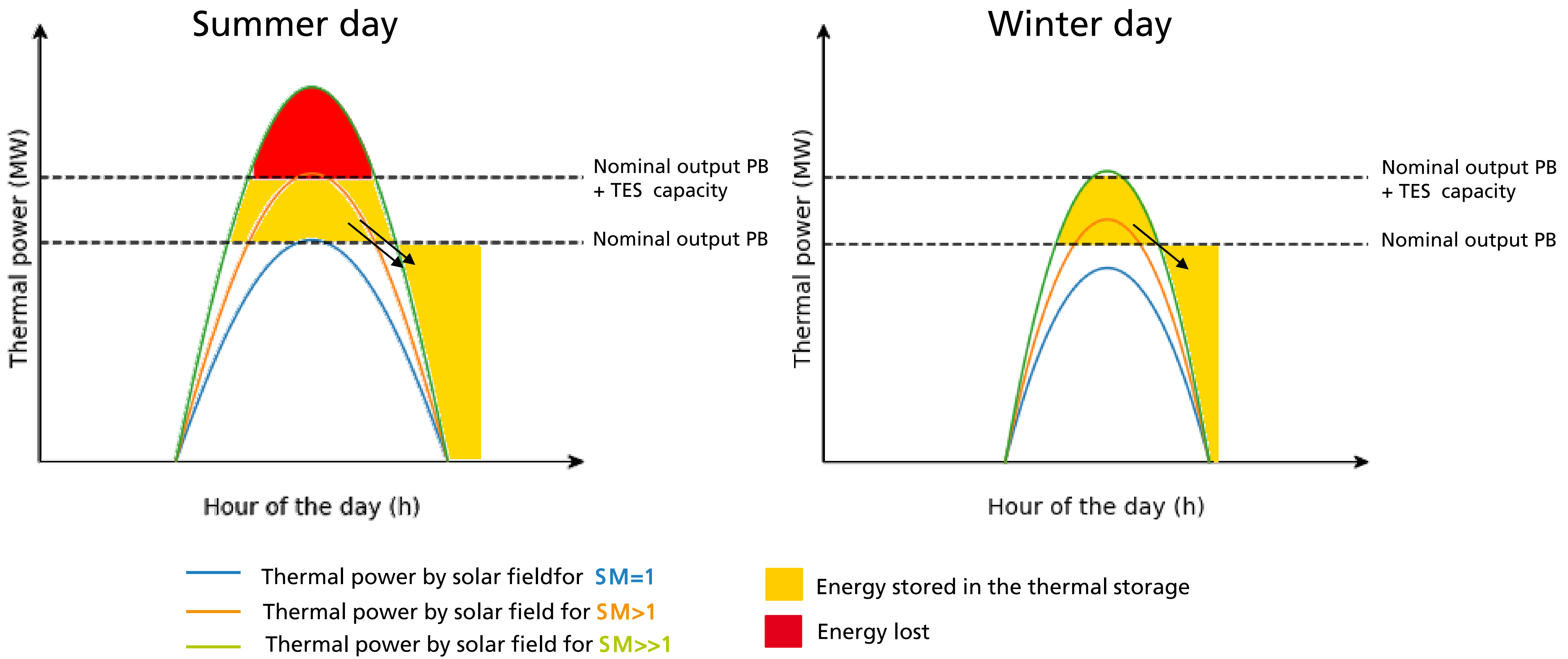


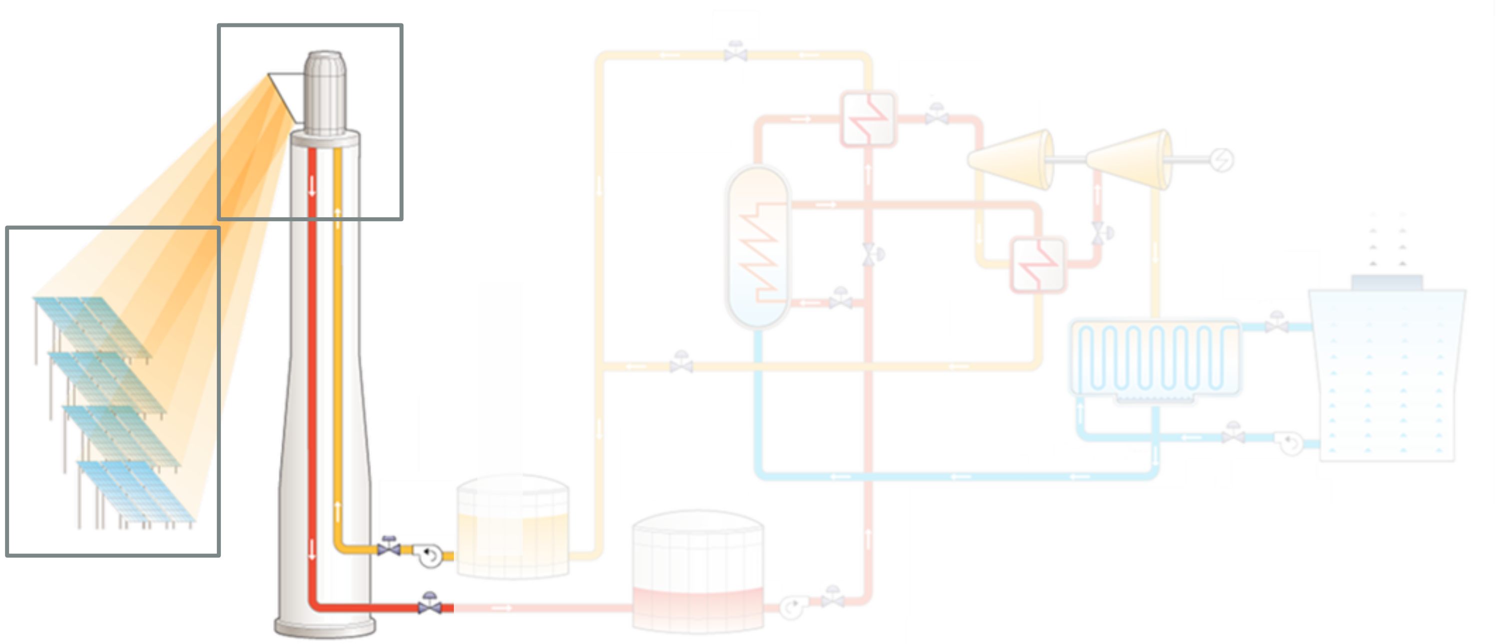
[1] Image adapted from: Abbas, Mohamed. (2013). Parametric Study of the installation of a Solar Power Tower plant under Saharan Climate of Algeria: case study of Tamanrasset.

Introduction

Heliostat field sizing factor

Ratio between the thermal power produced by the heliostat field at the design point and the thermal power required by the power block at nominal conditions.

$$HFSF = \left.\frac{\dot{Q}_{th,\,heliostat-field}}{\dot{Q}_{th,\,collector}}\right|_{design\_point}$$



[1] Image adapted from: Abbas, Mohamed. (2013). Parametric Study of the installation of a Solar Power Tower plant under Saharan Climate of Algeria: case study of Tamanrasset.

Methodology
Design and simulation

1. Component design

Preliminary plant design based on steady state thermodynamic models with $devISE_{CSP}$

2. Annual simulation

Dynamic hourly simulation for the designed plant with ColSim CSP

3. LCOE calculation

Evaluation of the LCOE of the plant to find the optimal solution

Methodology

Reference case: NOOR-III

The facility is located in southern Morocco (Ouarzazate) and was commissioned in 2018

Parameter	Value [4]
DNI	2500 kWh/m²/year
Turbine gross power	150 MW_{el}
Tower height	250 m
Storage capacity	7.5 h
Number of heliostats	7400
Heliostat aperture area	178.5 m^2
Receiver thermal power	660 MW_{th}

Parameter variation was performed for storage capacity, receiver and number of heliostats

[4] S. Relloso and Y. Gutiérrez. SENER Molten Salt Tower Technology. Ouarzazate NOOR III Case. AIP Conference Proceedings 1850, 030041 (2017); https://doi.org/10.1063/1.4984384

[5] Image adapted from: https://www.moroccoworldnews.com/public/2019/05/274576/noor-iii-morocco-performance-solar-energy

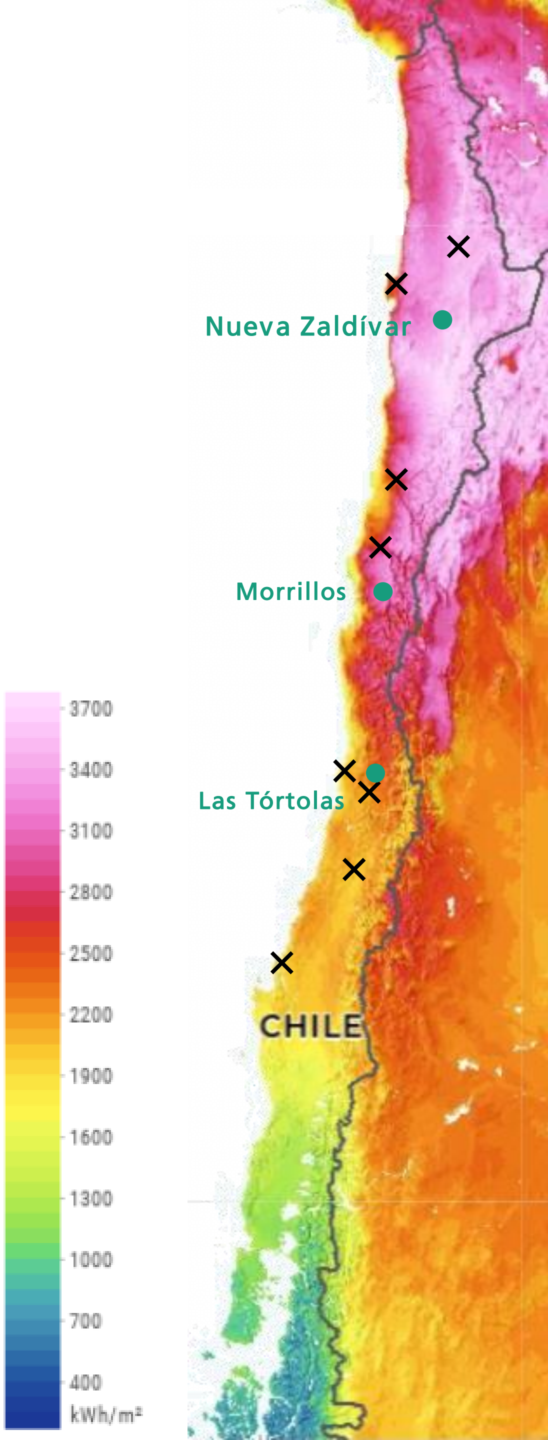
Methodology
Study cases

- Three sites selected:
  - Site 1: Las Tórtolas (Región Metropolitana de Santiago)

    Annual DNI: 2409 $kWh/m^2/year$ [2]
  - Site 2: Morrillos (Región de Coquimbo)

    Annual DNI: 3006 $kWh/m^2/year$ [2]
  - Site 3: Nueva Zaldivar (Región de Antofagasta)

    Annual DNI: 3585 $kWh/m^2/year$ [2]
- Hourly metrological data interpolated from closest Meteonorm stations. [6]
- DNI normalized with local data from Global Solar Atlas. [2]



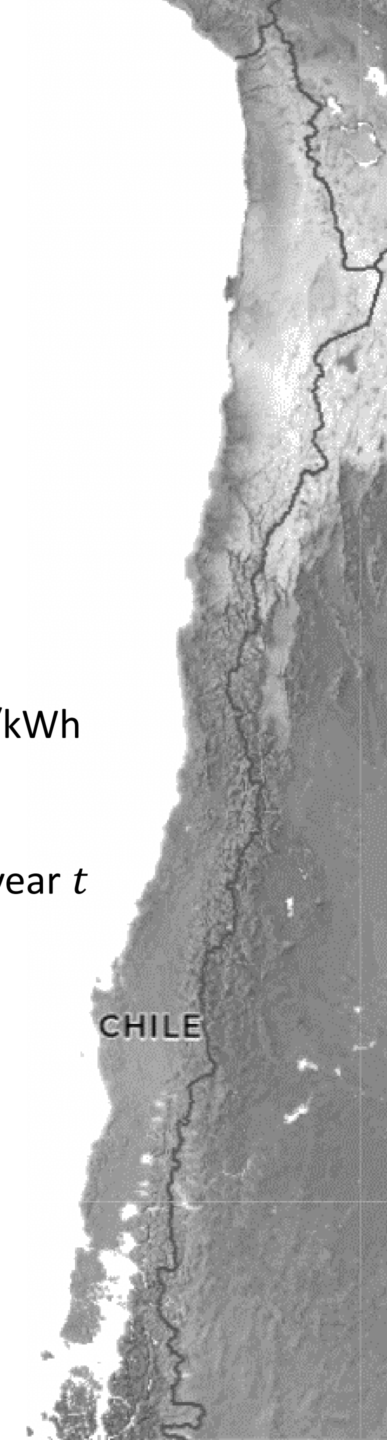
[2] Global Solar Atlas. https://globalsolaratlas.info/map
[6] Meteonorm. https://meteonorm.meteotest.ch/en/

Methodology
Cost assumptions

Parameter	Value [7]	Unit
Direct capital cost		
Heliostat field	100	€/m^2
Tower	61706	€/m
Receiver	70	€/kW$_{th}$
Power block	810	€/kW$_e$
Thermal storage	21	€/kWh$_{th}$
Indirect capital cost		
Site preparation	1	€/m^2
Soft costs (Project development, EPC margin)	20	% of direct cost
Operation and maintenance costs		
Annual O&M	3	% of investment cost
Annual insurance costs	0.7	% of investment cost

$$LCOE = \frac{CAPEX + \sum_{t=1}^{n} \frac{OPEX_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}}$$

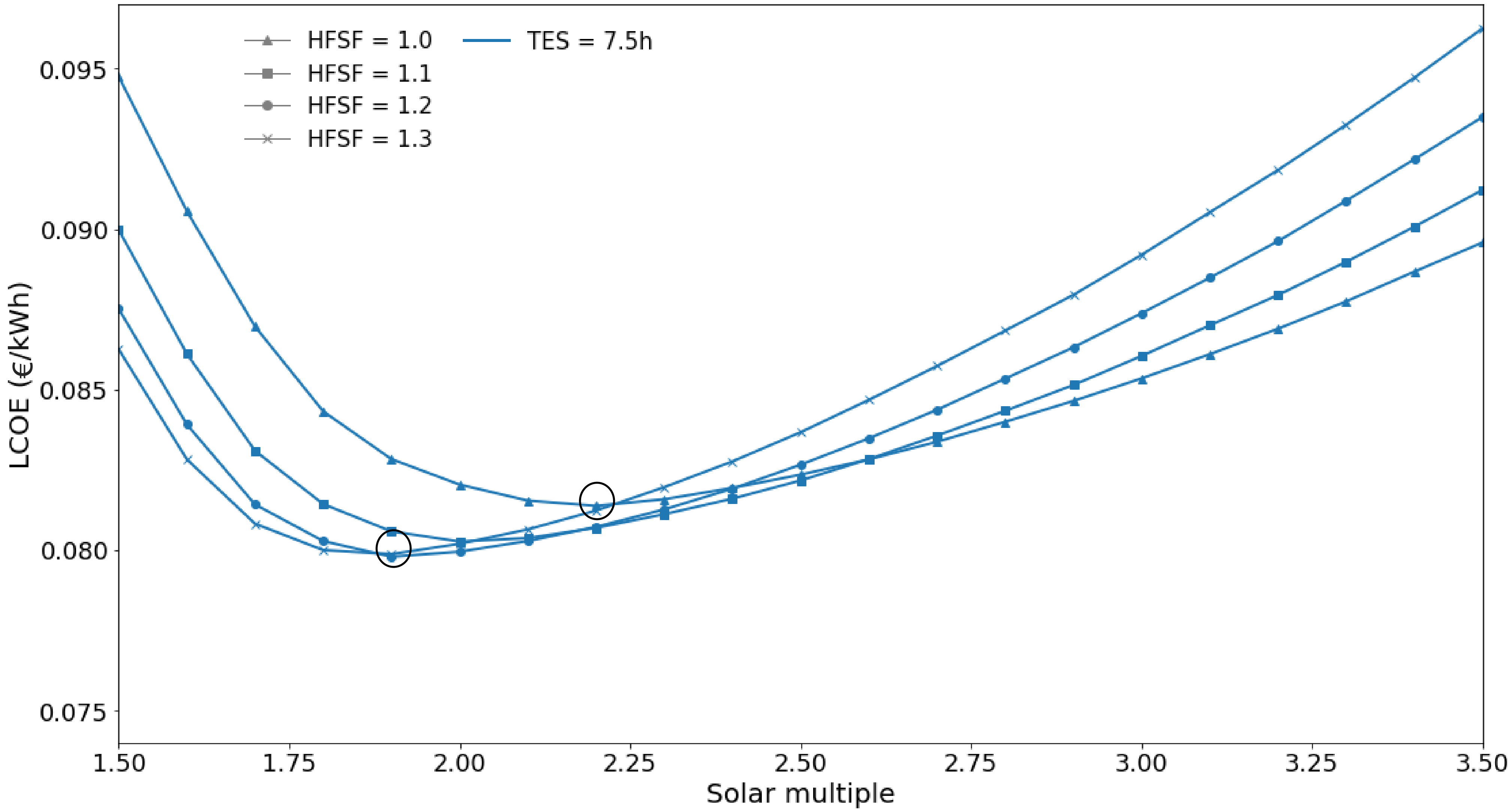
$LCOE$	Levelized Cost of Electricity in €/kWh
$CAPEX$	Capital expenditure in €
$OPEX_t$	Operating expenditure in € per year t
E_t	Produced amount of electricity in kWh per year
i	Real interest rate in %
n	Lifetime in years



[7] D. Juergen, J. Paucar, C. Schuhbauer, A. Schweitzer and A. Stryk. Blueprint for Molten Salt CSP Power Plant, Cologne, Germany. Final report of the research project "CSP-Reference Power Plant" No. 0324253 (2021).

Results

Parametric study: Nueva Zaldivar (Interest rate %5.5, plant lifetime 25 years)



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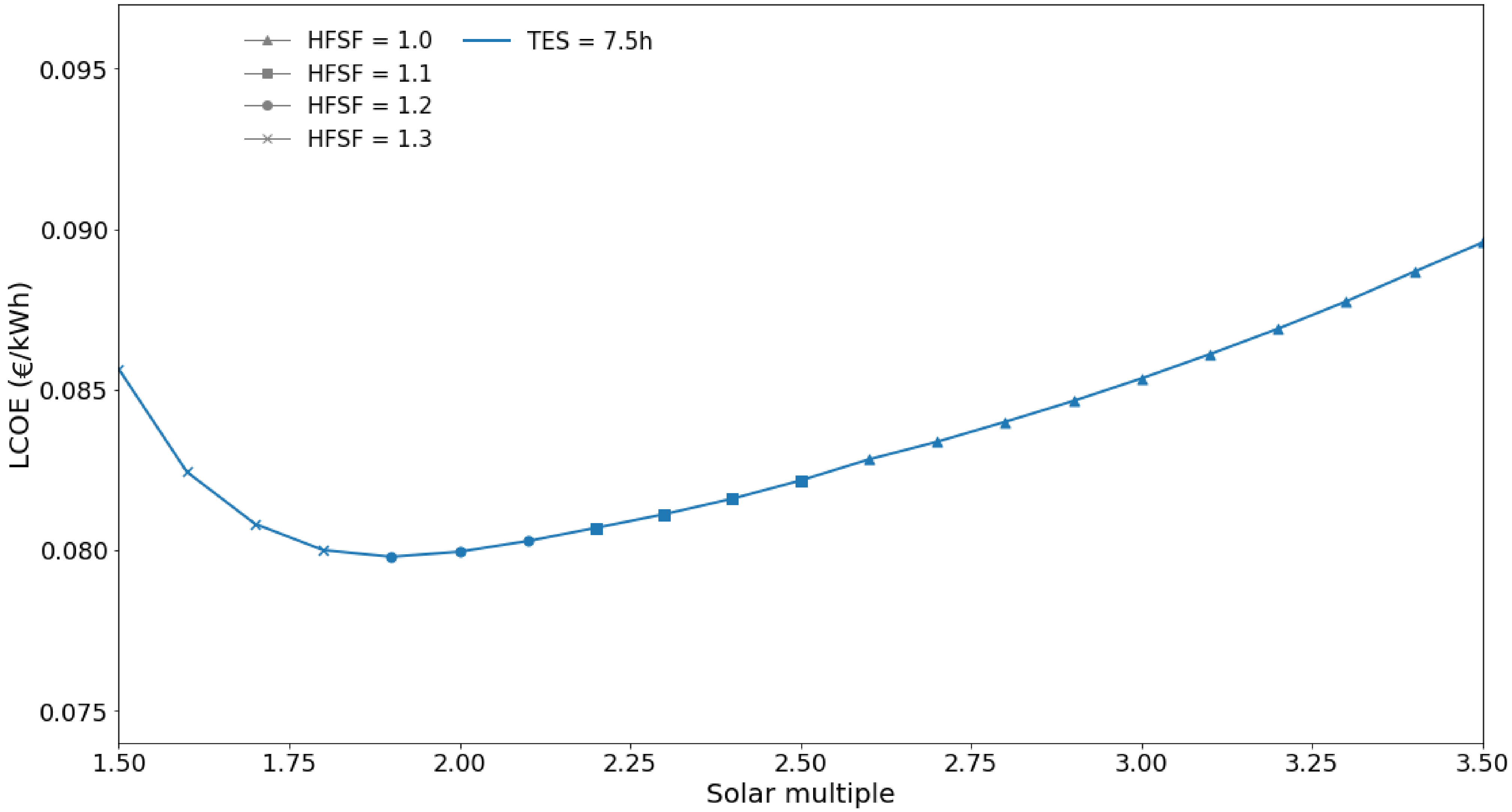

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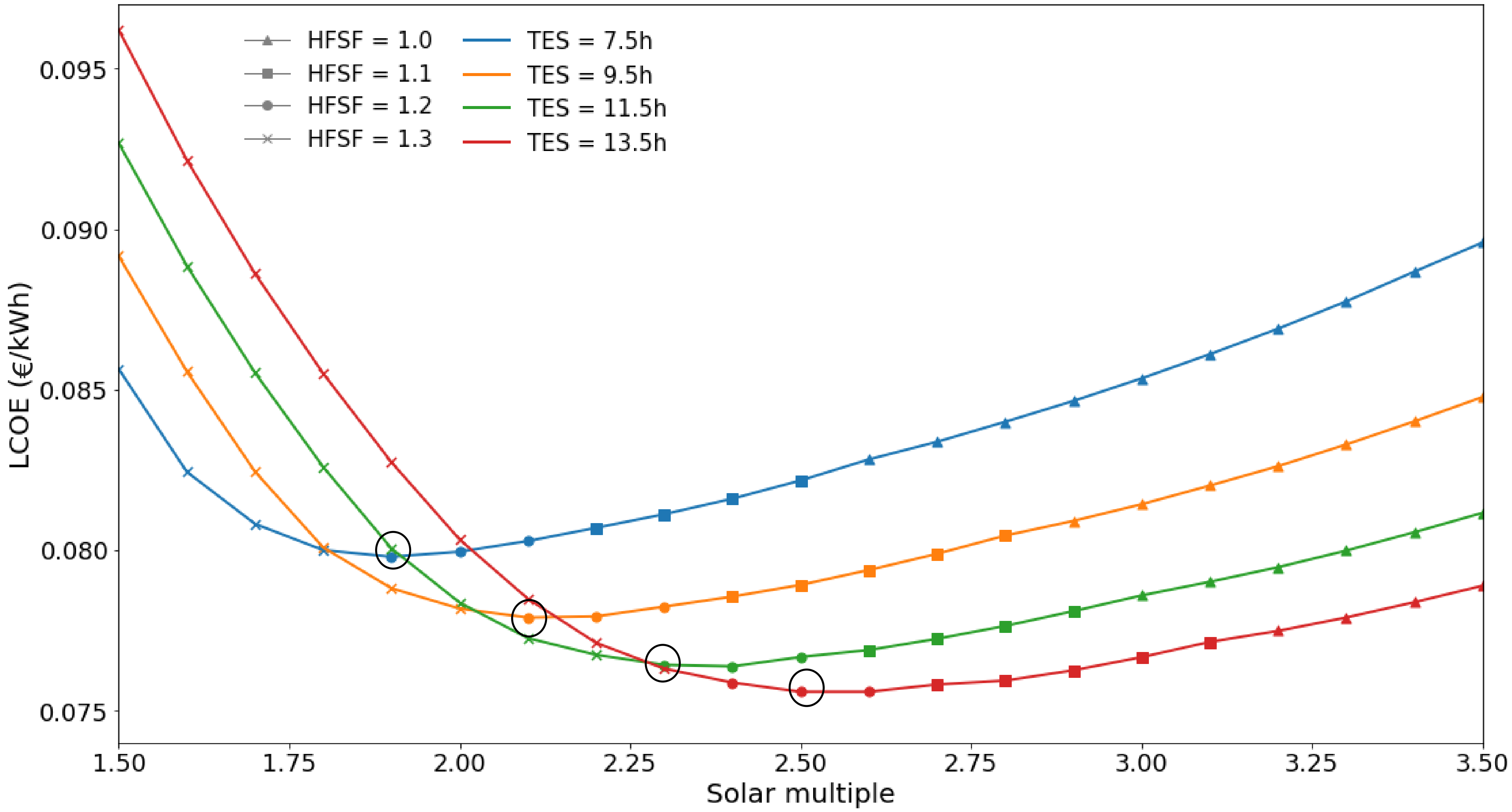
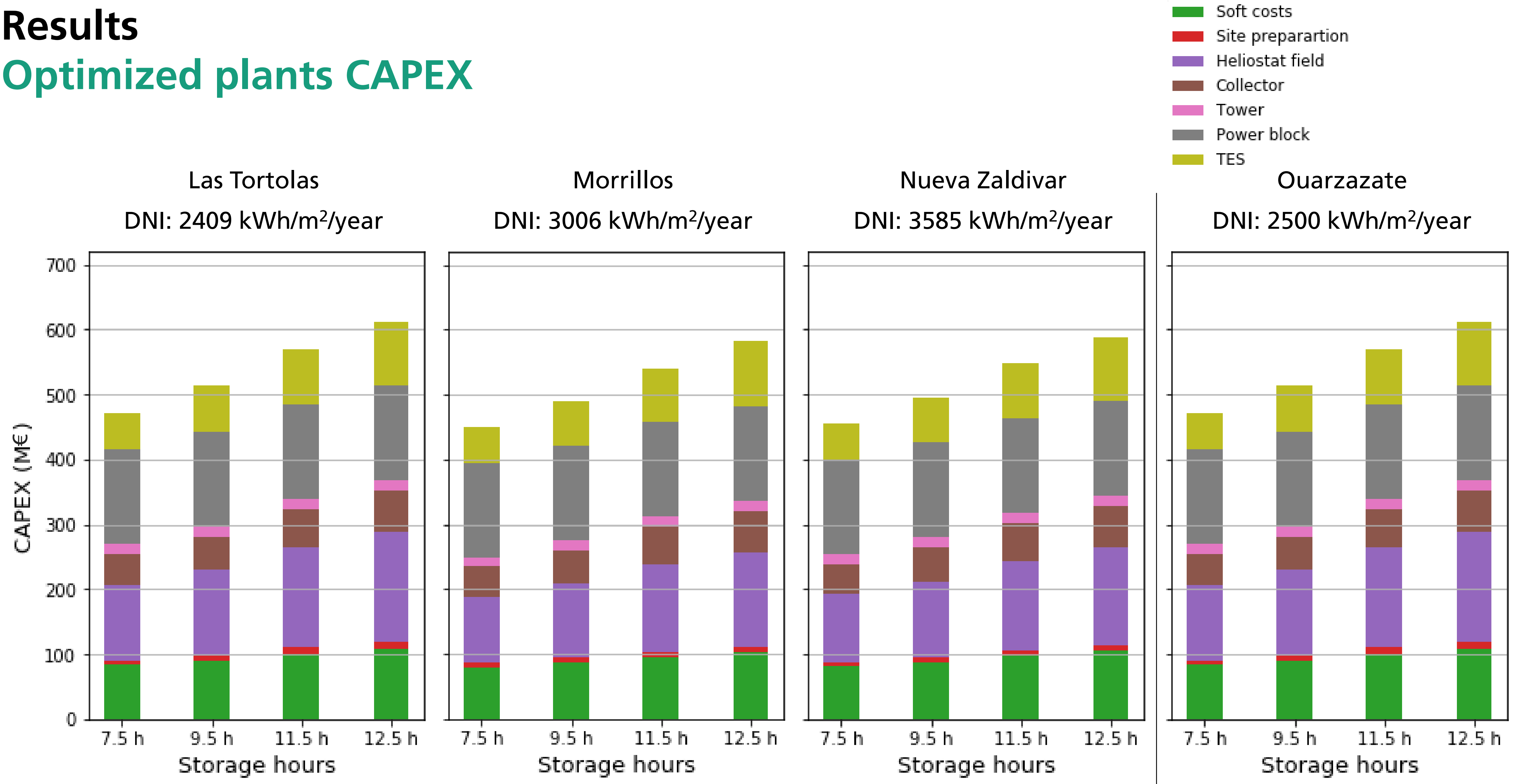
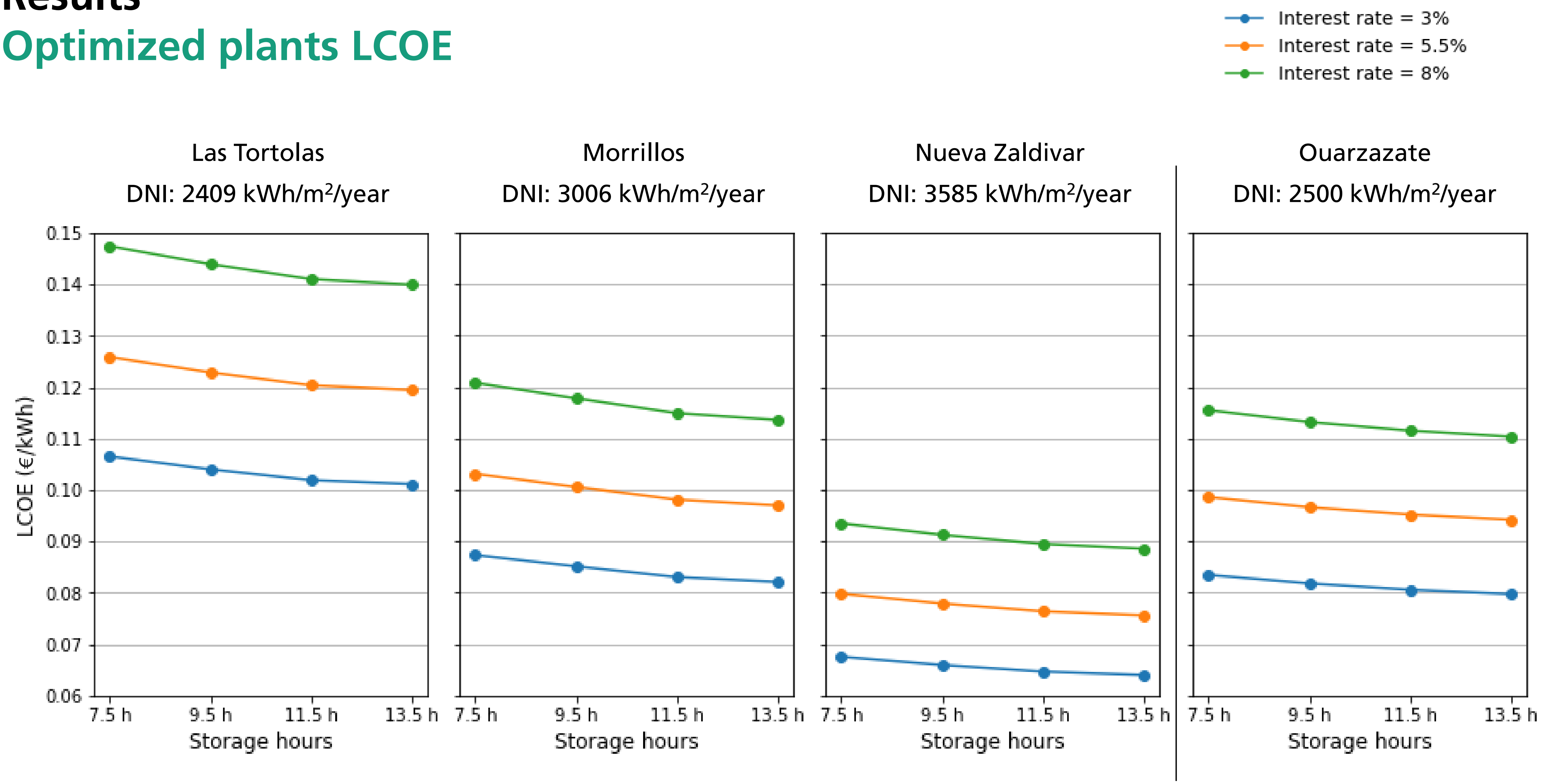


Results
Optimized plants CAPEX



Results
Optimized plants LCOE



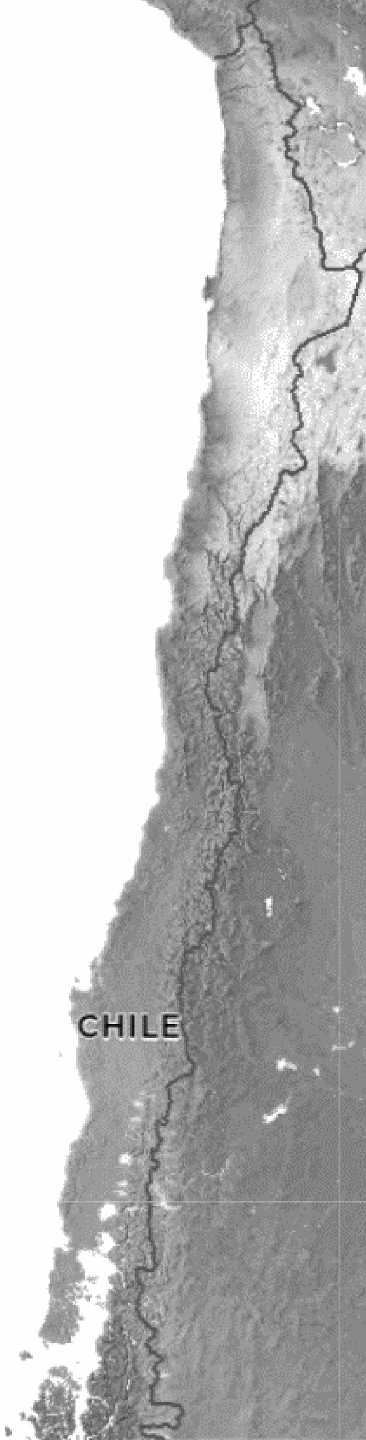
Conclusion

- Chile presents a lower LCOE than other typical CSP sites.

- A higher storage capacity lead to higher solar multiple, but heliostat field sizing factor remains constant.

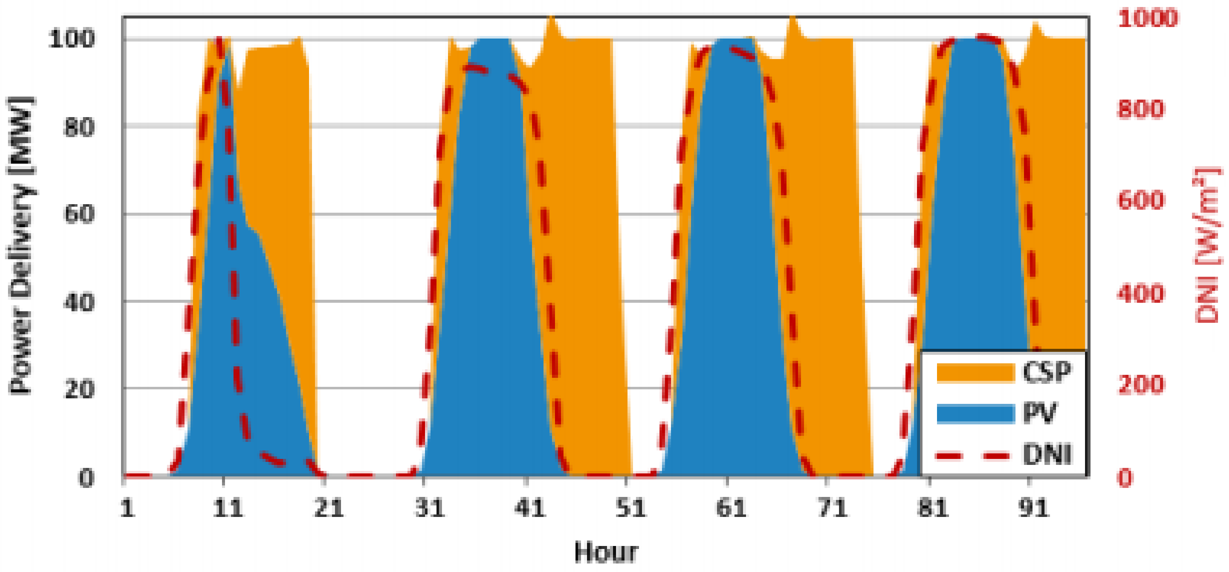
- Lower optimal solar multiple because of considering the heliostat field sizing factor: receiver size is further optimized.

- The tools ColSim CSP and devISE$_{CSP}$ developed in Fraunhofer ISE have the ability to simulate complex CSP systems in detail.



Outlook
CSP-PV hybridization

- Combining low cost of PV production and dispatchable power supply with cheap thermal storage of CSP.
- CSP-PV hybridization could further decrease the LCOE while increasing the capacity factor (above %64) and adapting to demand. [8]

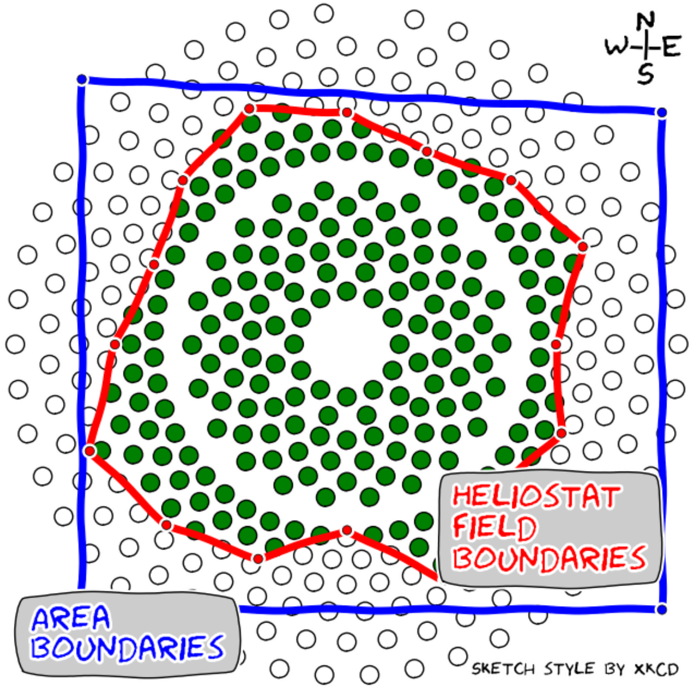


[8] N. Chandler, S. Rohani, T. Fluri. Techno-economic evaluation of system improvements within a CSP-PV hybrid plant. Solar Paces 2020.

Outlook
Heliostat field design with Polygon Optimization and Complex Boundaries

- Meet flux requirements
- Optimize for flexible objective function
- Allowable flux constraints
- Coherent fields
- Complex area boundaries

- Polygon-based heliostat selection
- Optimization with *evolution strategies*



[9] P. Schöttl, S. Rohani, E. Leonardi, L. Pisani, I. Les, A. Mutuaberria, P. Nitz. Solar field heliostat selection based on polygon optimization and boundaries AIP Conference Proceedings 2126, 030053 (2019); https://doi.org/10.1063/1.5117565

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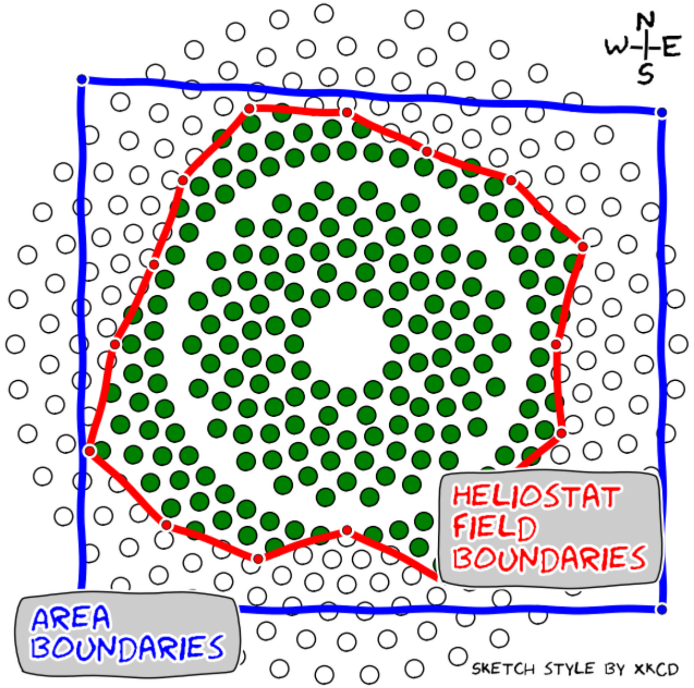

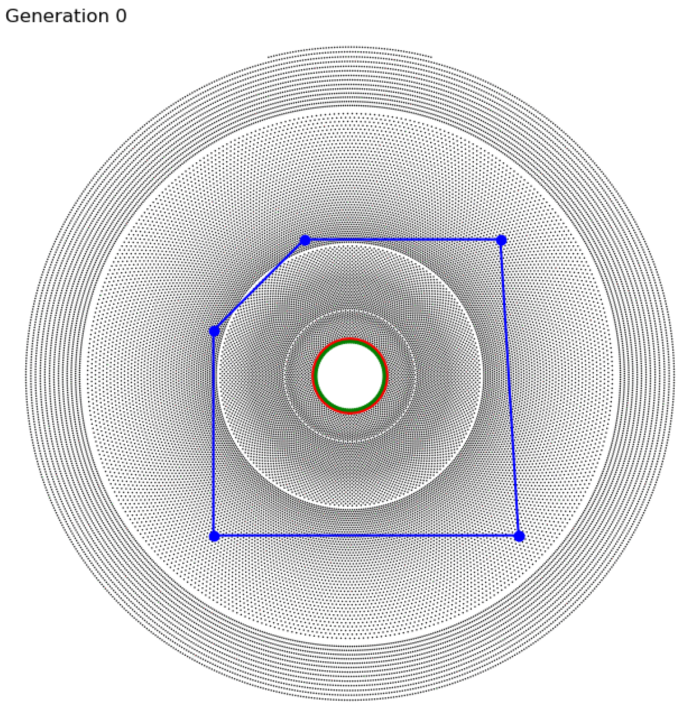

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Thank You for Your Attention!

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