Comparative Techno-economic Analysis of Different Parabolic Trough CSP Plants for the Italian Market

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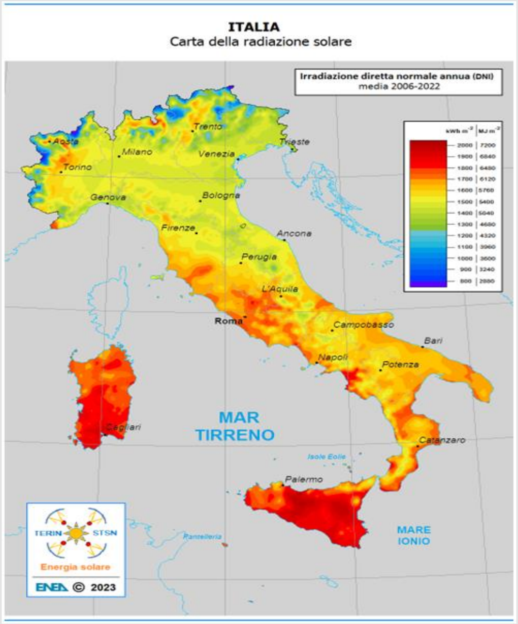
Introduction

Italian DNI distribution

217 km2 with DNI > 2000 kWh/m2Y



Italian CSP potential

- In 2001 it started the Italian demonstration R&D programme for CSP
- The Italian National Integrated Energy and Climate Plan (PNIEC) identified CSP as a technology that is still uneconomic in the Italian context
- The Italian Incentives for CSP period 2024-2028 was set by Decree 19th June 2024
- updated cost estimates for CSP relevant to the current Italian market

Methodology

Cross-validation:

- CSP plants based on parabolic trough (PT) 50 MW – 2 tanks
- Two distinct modelling tools, developed by ENEA (MATLAB - version 2023a) and DL (Greenius software (version 4.11))
- TMY were generated by ENEA based on their own model for the radiation

Range of scenarios:

- 3 HTFs (Therminol VP1, ternary molten salt mixture (NaKCa-NO_3, YARA-MOST) and Solar Salt (KNO_3-$NaNO_3$;
- 2 locations: Gela (1968, and Montalto di Castro (1832 [kWh/m^2]);
- 3 different values for the thermal energy storage (TES) 9, 12 and 15 full load hours.

Methodology

Quasi-dynamic approach with a one-hour timestep;

SF,PB,TS three models;

The SF,PB,TS models are connected via an operating strategy:

- PB operative
- how the solar is spread between TS and PB

	Unit	VP1	YARA	Solar Salt
Solar field cost	[€/m^2_{ap}]	260	280	280
TES cost	[€/kWh_{th}]	55	30	25
Cost of natural gas	[€/kWh_{th}]	0.11	0.11	0.11
Specific land price	[€/m²]	2	2	2
Surcharge for EPC	[%]	20	20	20
Interest rate	[%]	8	8	8
Lifetime	[a]	25	25	25
Annual ins. costs	[%]	0.7	0.7	0.7
Annual HTF replac.	[%/a]	1	0	0
Annual O&M costs	[%]	2	2	2
Electricity	[€/MWh]	88	88	88

Performance Model description

Power Block

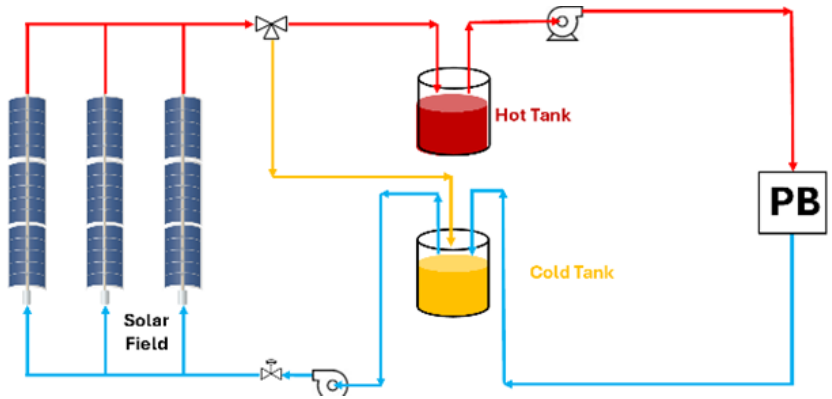
- The power block has been modelled in EBSILON Professional (version 16.0)
- The same part load curve was used for all power blocks
- only the nominal gross efficiency of the power block was varied
- full load operation for all time

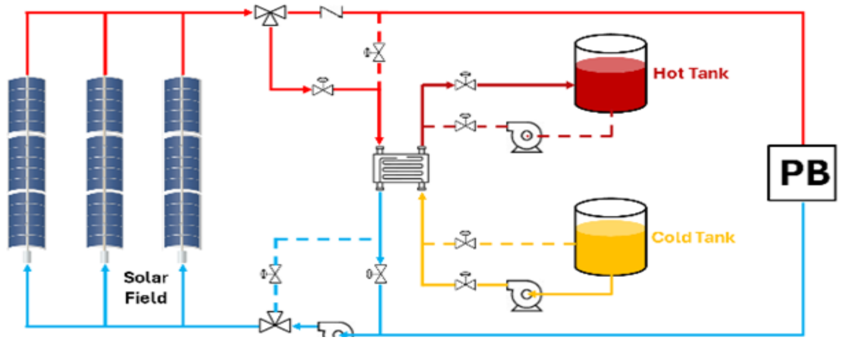
Solar field

- the energy absorbed by the receiver tube is given by

  $Q_{abs}=\eta_{(optical,0)}\ \eta_{shadow}\ \eta_{endloss}\ \eta_{clean}\ A_{SF}\ \mathbf{IAM(\theta)}\ E_b$
- The heat losses experimentally determined : $Q_{(loss,HCE)}=q_{loss}\ A_{SF}$
- heat losses in piping: $Q_{(loss,pipe)}=h_{(loss,pipe)}\ A_{SF}\ \Delta T$

Performance Model description





- the minimal accepted temperature for the ternary salt mixture is 170 °C and for Solar Salt 270 °C
- The antifreeze heat is introduced to the system from thermal storage or supplied by an external heater fired

$$\eta_{plant}=\eta_{optical}\ \eta_{thermal}\ \eta_{piping}\ \eta_{storage}\ \eta_{(power\ block)}$$

$$\eta_{plant}=P_{el}/P_{sun}$$

Performance Models description

ENEA model

- the sun position is calculated using an ENEA owner algorithm;
- the net heat output delivered by the solar field is calculated using a model proposed by Forristal;
- the TES model, the mass and energy balance equations of the two tanks, the thermal losses were evaluated as a function of actual fluid temperatures in the tanks;
- **the freeze protection has been supplied by an external gas-fired heater;**

DLR model

- the sun position is calculated using the NREL;
- the net heat output delivered by the solar field is calculated balance of energy of solar field where the thermal inertia of the solar field is used to model the heat-up and cool down.
- the two-tank molten salt thermal storage is modelled as an energy accumulator with a constant heat loss, independent of the state-of-charge;
- **the freeze protection is done primarily by using solar heat from the thermal storage**

Simulations

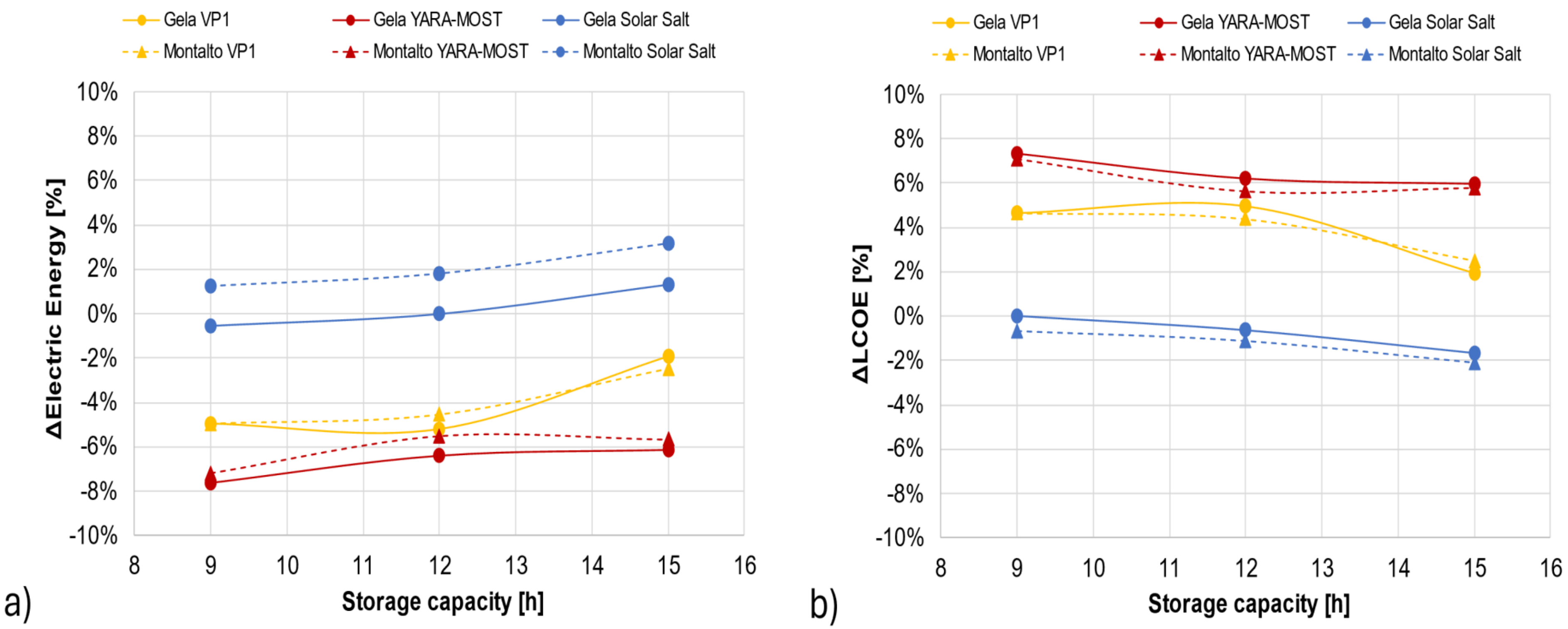
Main parameters simulations

	Unit	VP1	YARA-MOST	Solar Salt
Collector type/name		HelioTrough	HelioTrough	ENEA
Aperture area	[m²]	1263	1263	566.4
Aperture width (gross)	[m]	6.77	6.77	5.9
Collector length (gross)	[m]	193	193	100
Mean cleanliness of collect.	[%]	97	97	97
HCE diameter (inner/ outer)	[mm]	84.6 / 89	75.6 / 80	64 / 70
Nominal optical efficiency	[%]	81.6	81.2	79.7
Nominal outlet/inlet temp.	[°C]	393/298	500/290	550/290
Collectors per loop	[-]	4	6	6
Minimum temp. (Antifreeze)	[°C]	60	170	270
SF parasitics for pumping	[W_{el}/ m^2_{ap}]	~6.3	~2.9	~1.4
SF par. for control and track.	[W_{el}/ m^2_{ap}]	1.0	1.0	1.8
Storage medium		Solar Salt	YARA	Solar Salt
HTF temp. charge / disch.	[°C]	393 / 379	500 / 500	550 / 550
Temp. of storage medium	[°C]	386 / 285	500 / 290	550 /290
Steam temperature	[°C]	386	490	540
Nominal PB gross efficiency	[%]	~39	~42	~43.5

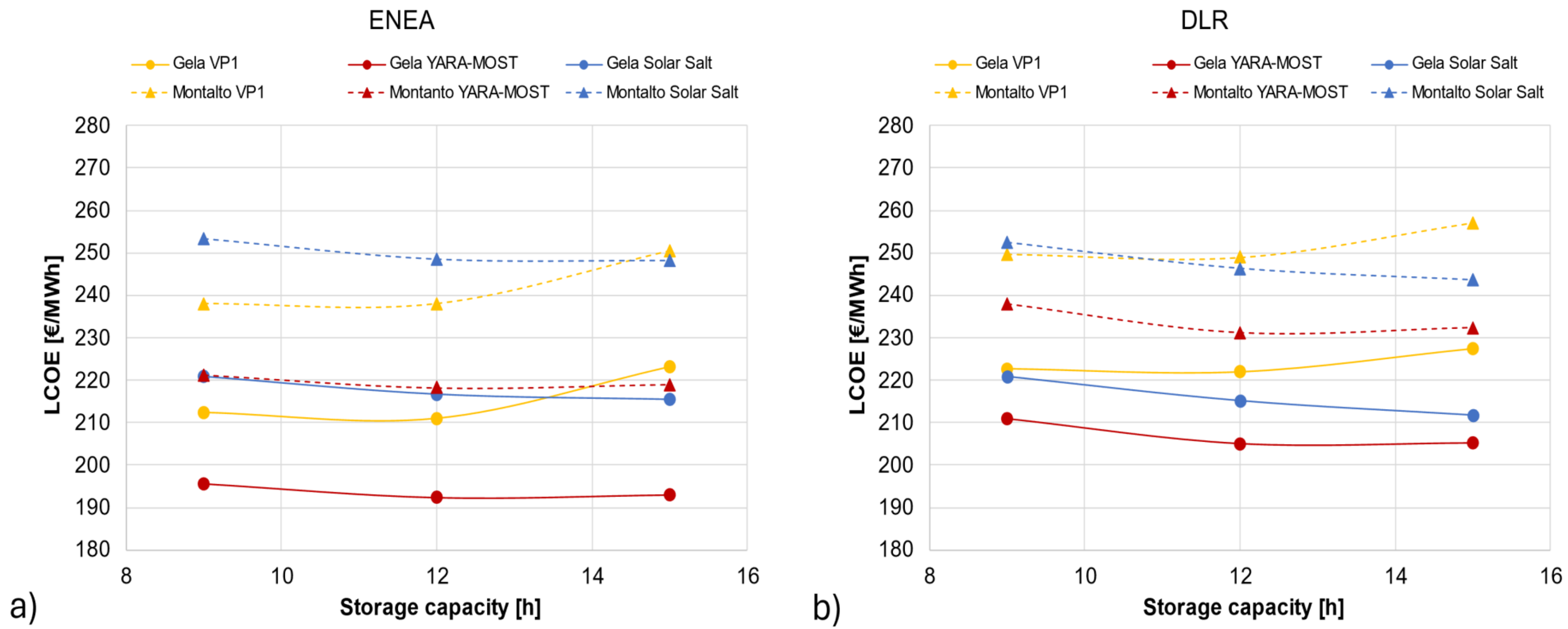
Working Strategies

- All plants charge the TS during daylight hours, electricity is produced as soon as
  - TES capacity allows PB operation
  - storage capacity is fixed to full load test target (9, 12 or 15h);
- The operation strategy with sunrise:
  - the SF is focused and started up,
  - the energy is sent to the TES system;
  - the PB starts when TES is sufficiently filled to do start-up procedure.
  - the PB runs until the TES is empty.

Simulation Comparison between the two Models



LCOE simulations scenarios



Conclusions

The analysis presented here are the preliminary elaborations which use conservative assumptions, considers the high energy costs in Italy and a lack of economy of scale in the supply chain, and already accounts for the inflation waves experienced after 2020. In addition, the selected sites are in the low range of DNI to be profitable.

- the results of both models are aligned especially for the study case based on plants that employ MS binary. The discrepancies in other two cases could be mainly due to difference approach employ by two models in the calculation of the heat needs for the freeze protection.

- the plants with YARA-MOST show the lowest values: these results are interesting and promising even if there is fewer operating experience with the use of ternary salt compared to Solar Salt and VP1

Conclusions

- The analysis of the behavior of plants with YARA-MOST require a deep analysis in consideration of the real max/min operative temperatures that can reach during the plant operation;

- The case with CSP plant based on using VP1 should be repeated with silicon oil
- the LCOE values are in the range 192-257 €/MWh, which is considerably higher than the prices announced for new CSP projects in the last years Referring to the specific costs Salt system presented in a pre-2019 paper [C. A. Pan, R. Guédez, F. Dinter, T. M. Harms, "A techno-economic comparative analysis of thermal oil and molten salt parabolic trough power plants with molten salt solar towers", SolarPACES 2018], we obtain that LCOE values range from 145 to 194 €/MWh;

Thanks for kind attention

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This study is partly supported by:
EuroPaTMoS project - CSP ERANET, EU Horizon programme G.A. 838311.
SALTOpower, Horizon programme, G.A. No: 101079303