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WtE efficiency improvements: integration with solar thermal energy

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Outline

- Introduction
- Objectives/Integration
- Simulation/assumptions
- Economic analysis assumptions
- Results - thermodynamics
- Results - economics
- Conclusions

Introduction

WtE Energy efficiency:

- large scale WtE plants may reach up to 30-31% net electric efficiency, in only power mode
- small-medium size incineration plants generally operate with steam at 40-50 bar and 400 °C, with maximum net electric efficiency around 20-24%

Efficiency improvement: Increase of the steam parameters

Limitations:

- acidic corrosion (the metal chlorides in the fly ash , high concentration of hydrogen chloride (HCl) in the flue gas
- increasing investment costs

Introduction

WtE efficiency improvements, examples of alternative configurations:

- superheating of live steam from 400 °C to 520 °C in an external superheater, consisting of natural gas fired boiler (WtE plant in Heringen, Germany).

Overall energy efficiencies of the power plants can be significantly improved through the solar integration

Available CSP technologies:

parabolic trough collector (PTC)
solar power tower (SPT)
linear Fresnel reflector (LFR)
parabolic dish systems (PDS).

Objective

- **Initial thermodynamic and economic assessment in order to understand the possibilities and the benefits of an WtE and CSP integration by superheating the steam produced by the WtE flue gas boiler in the solar power tower facility.**

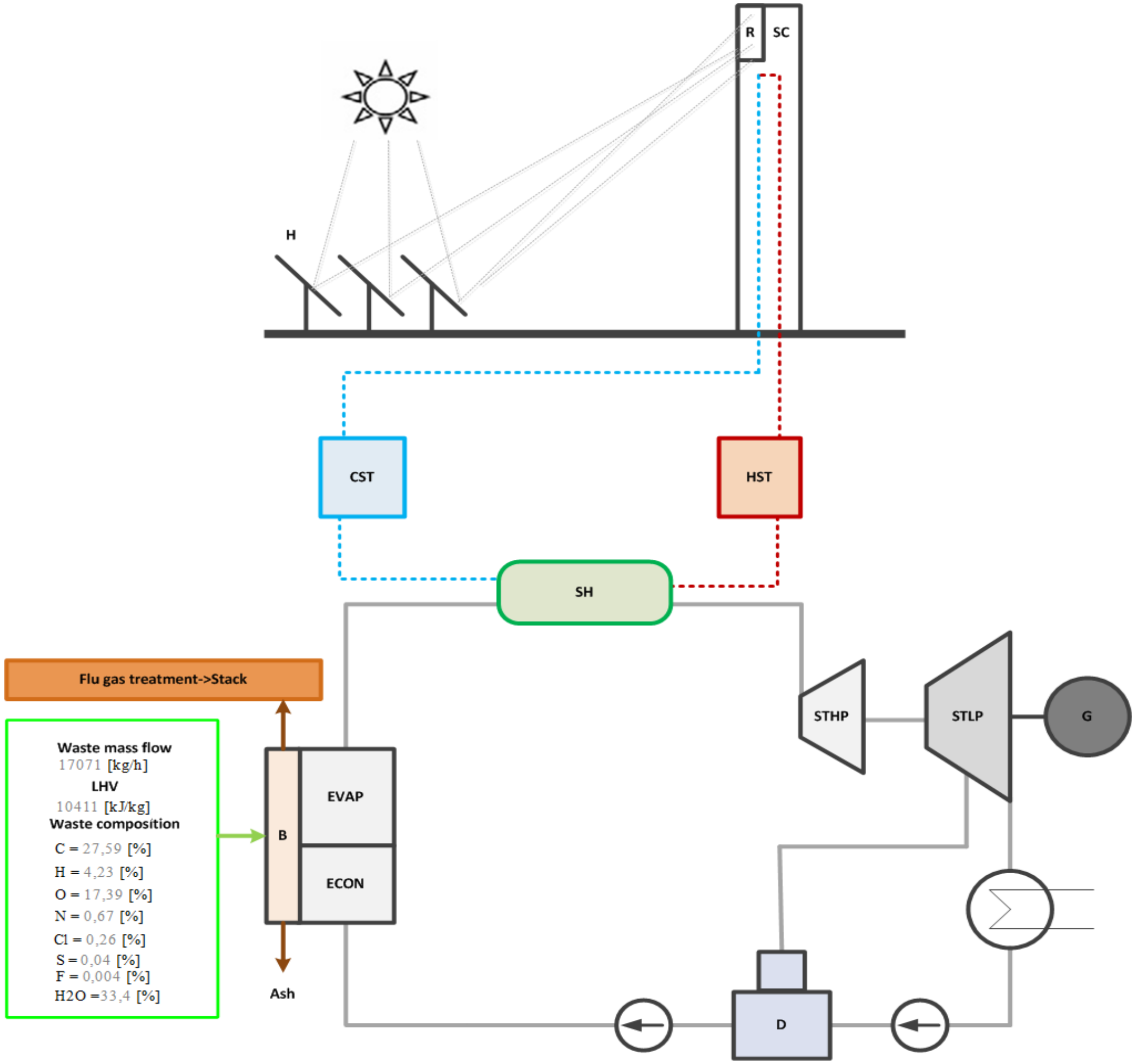
The main questions the authors would like to answer at this stage are:

How much the CSP integration will influence the thermodynamic performance and overall plant cost?

Parametric study:

Analysis of the effects of the most important steam cycle parameters and configuration on the thermodynamic and economic performance of a WtE plant.

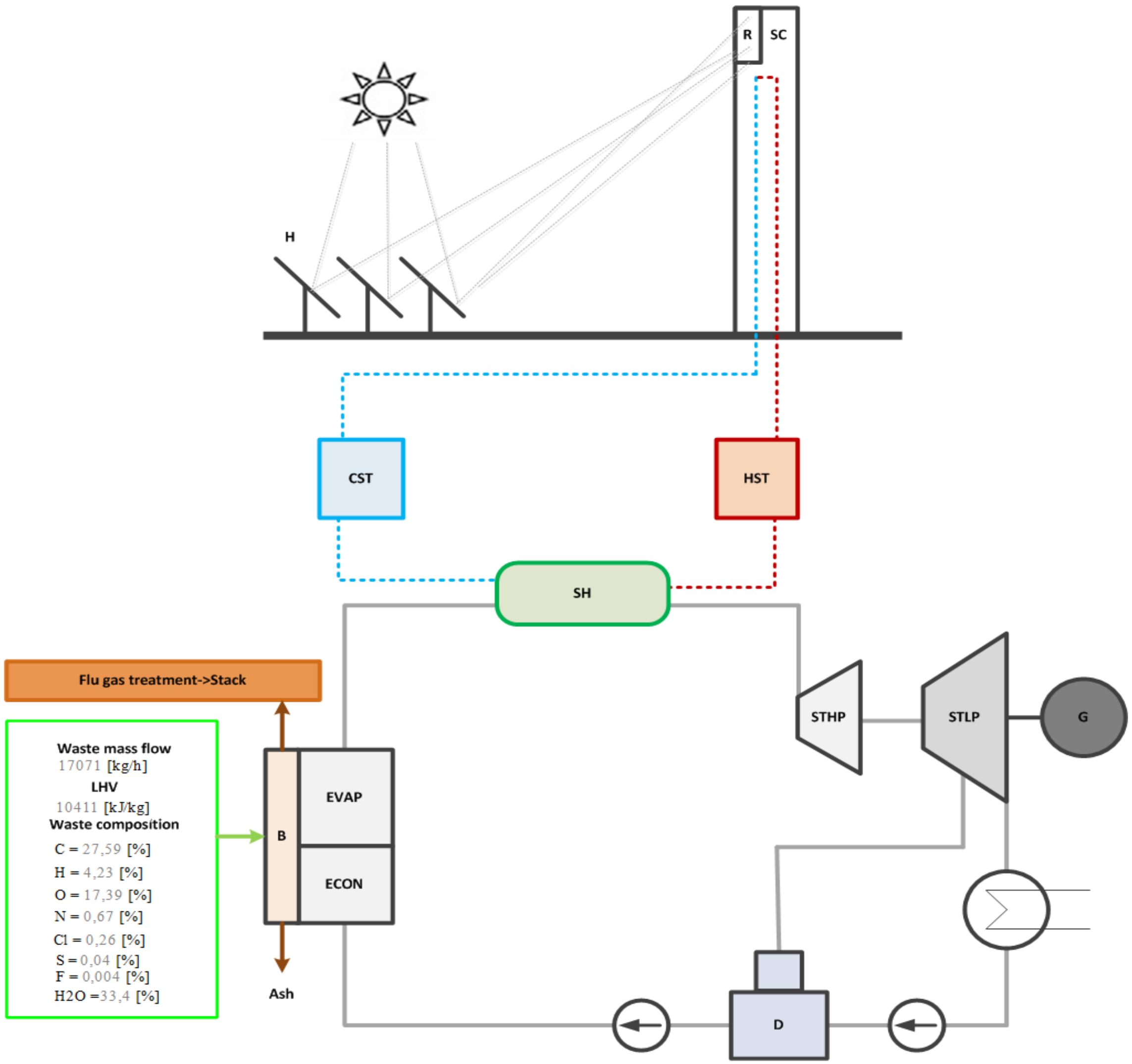
Integration



The proposed case study is a simplified structure operating at nominal parameters, yet correctly representing the transformations of energy in subsequent devices.

- ✓WtE part - based on the integrated boiler grid furnace (B) fueled by MSW.
- ✓CSP part – molten salts mixture (60% $NaNO_3$ and 40% by KNO_3) is considered as the working fluid, in the solar receiver (SC).
- ✓Heat generated in the solar cycle is transferred to the bottoming WtE cycle, by means of the heat exchanger (SH).
- ✓Superheated steam feeds the steam turbine (STHP-STLP).

Integration



- ✓ Conventional steady-state mass balances (involving stoichiometry) and energy balances for the WtE part were resolved by a home developed thermodynamic model (using Engineering Equation Solver, F-Chart Software).
- ✓ Operational problems like part-load characteristics, non-steady operation with heat storage, the temporal distribution of demand and control strategies, etc. are not discussed.
- ✓ Usable products: electricity (net power output). Heat production is not considered in this study.
- ✓ Fixed: capacity of the WtE plant, MSW composition, MSW mass flow rate and LHV

WtE simulation

Main assumption and design parameters for the WtE simulation
Base case of standalone WtE:

Thermal power input - plant size [MW]	50
MSW throughput [Mg/y]	135,199
MSW LHV [MJ/kg]	10,5
Steam maximum pressure [bar]	40
Steam maximum temperature [°C]	400
Steam mass flow [Mg/h]	54.3
O_2 in the flue gas at the boiler exit [% vol.]	6.5
Flue gas temperature at the stack [°C]	135
Turbine isentropic efficiency	0.78
Gross power output [MW]	**12.6**
Self-consumption rate, %	**13.8**
Net electrical efficiency	**0.22**

Simulation conditions

Parametric study:

T_{SH}: 400°C - 520 °C (the upper limit is imposed by the maximum temperature allowable for the molten salts)	p_{SH}: 51 - 120 bars (the lower limit is imposed by the minimum temperature imposed for the salts, - solidification at 290 °C, T_{pinch}: 25 °C)	Varying DNI values ranging from 500 to 1000 W/m^2.

Economic assessment

Economic assesement, WtE part

$$C_{WtE} = C_{fix,WtE} + \left(0.1 \times C_{th,WtE} + 0.9 \times C_{th,WtE}\left(\frac{m_{vap}}{m_{vap,ref}}\right)^{0.7}\right)$$

Fixed part: the waste supply system, ash handling system, flue gas treatment, water supply and treatment system, electrical system, automatic and control system**. The contribution of this fixed system was assumed as 38%**.

Scaled part: The cost of thermal part of the WtE – i.e. mainly boiler and steam cycle – was assumed to change according to the change in the generated steam mass flow rate.

The total investment cost of a reference stand-alone WtE were assumed on the basis of the total plant cost of about 58 MW WtE plant operating In Italy.

Economic assessment

Economic assesement, cost assumptions

$$C_{WtE} = C_{fix,WtE} + \left(0.1 \times C_{th,WtE} + 0.9 \times C_{th,WtE} \left(\frac{m_{vap}}{m_{vap,ref}}\right)^{0.7}\right)$$

Main assumption for the economic analysis

Investment cost of reference WtE (58 MW) unit, mln€	**111,774**
Specific cost of reference WtE unit, €/kW$_{LHV}$	1 899
Specific cost of reference WtE unit, €/kW$_{net}$	9 503
Specific cost of solar field, € /m²	**200***
Specific cost of thermal storage system, € /kWh	**30***
Specific cost of tower and receiver, € /MW	**200***

*Avila-Marin AL, Fernandez-Reche J, Tellez FM. Evaluation of the potential of central receiver solar power plants: Configuration, optimization and trends. Appl Energy 2013;112:274–88. doi:10.1016/j.apenergy.2013.05.049.

Results - thermodynamic analysis

Gross power output: 15.7 to 20.3 MW , <u>WtE stand-alone 12.6 MW</u>

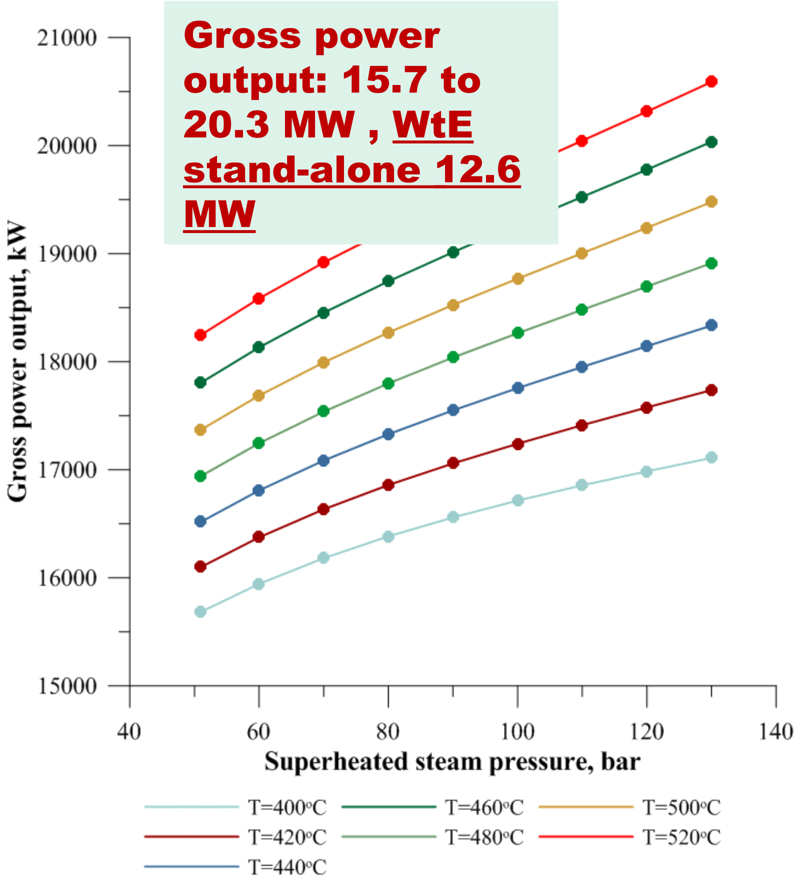


Fig.1 Gross power output as a function of temperature and pressure of superheated steam (DNI=600 W/m²)

The power output is not affected by the different DNI conditions

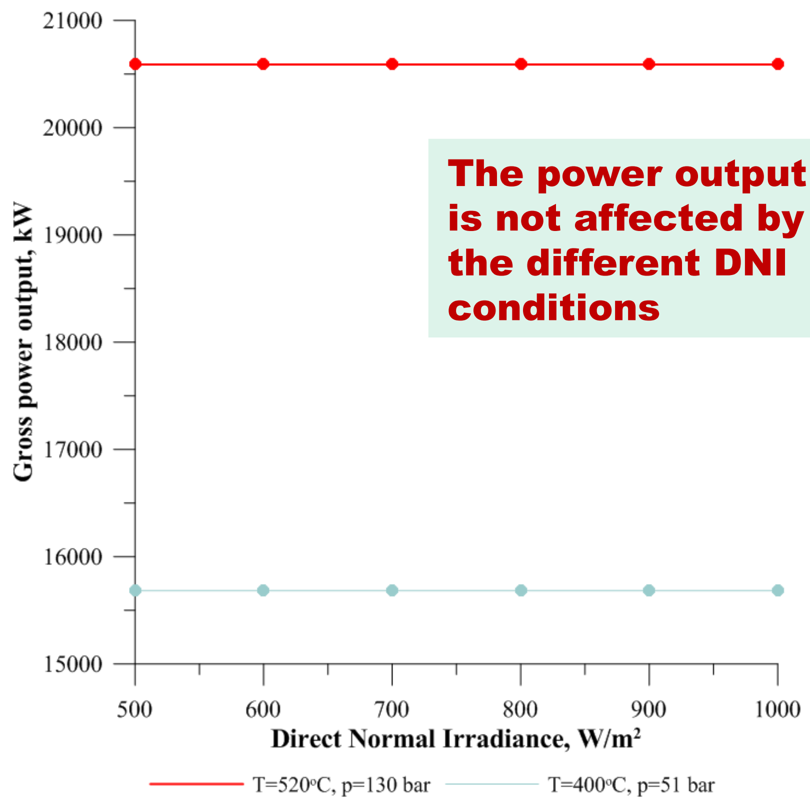


Fig.2 Gross power output as a function of direct normal irradiance

Results - thermodynamic analysis

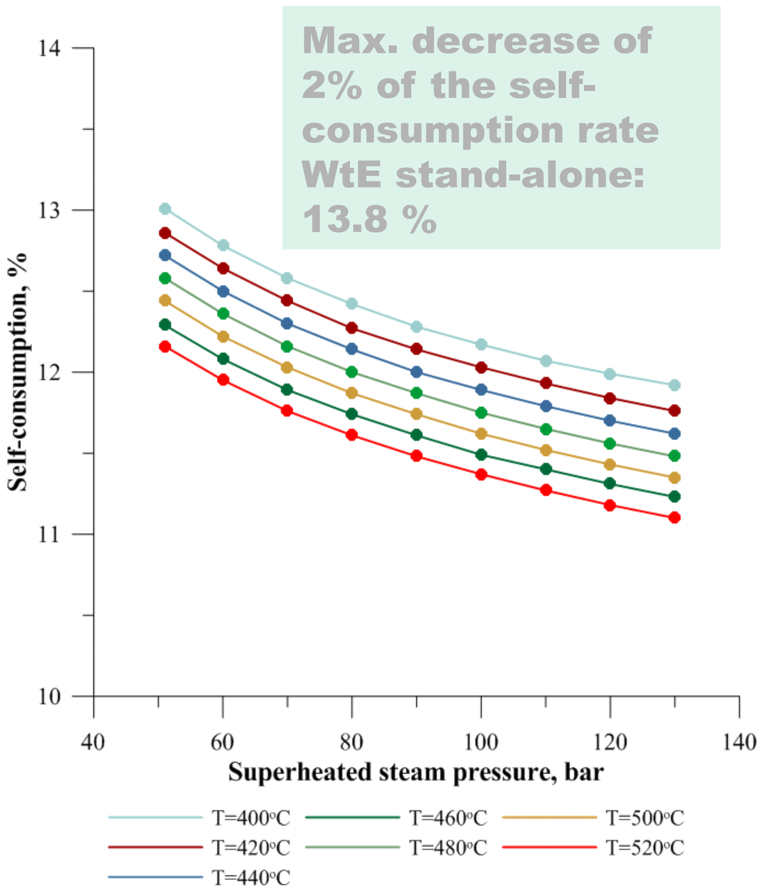


Fig.3 Self-consumption rate as a function of temperature and pressure of superheated steam (DNI=600 W/m²)

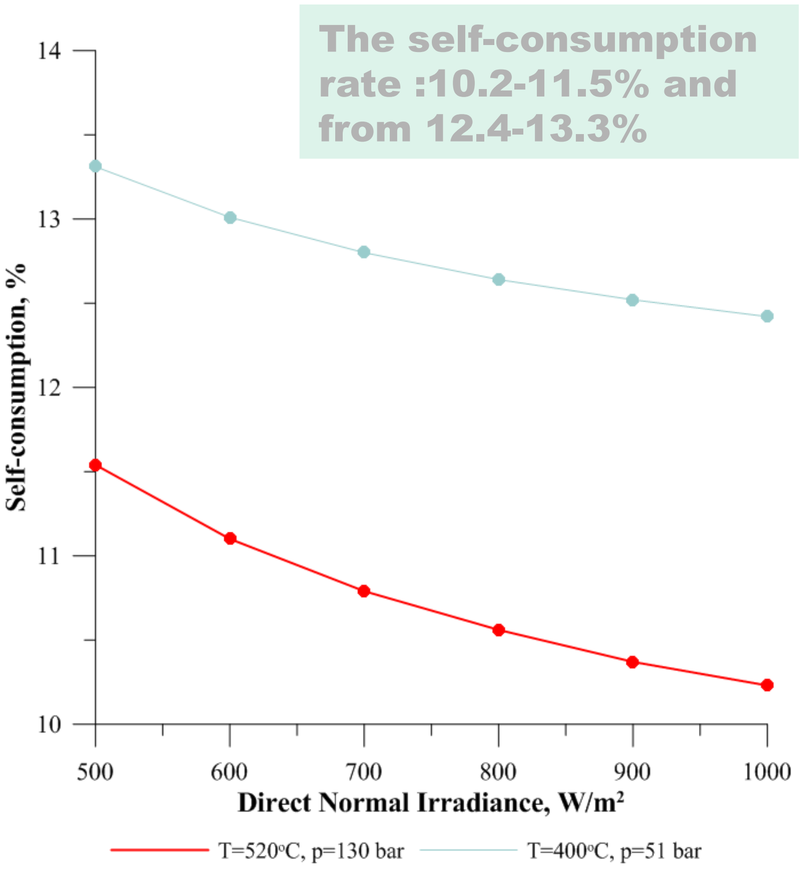


Fig.4 Self-consumption rate as a function of direct normal irradiance

Results - thermodynamic analysis

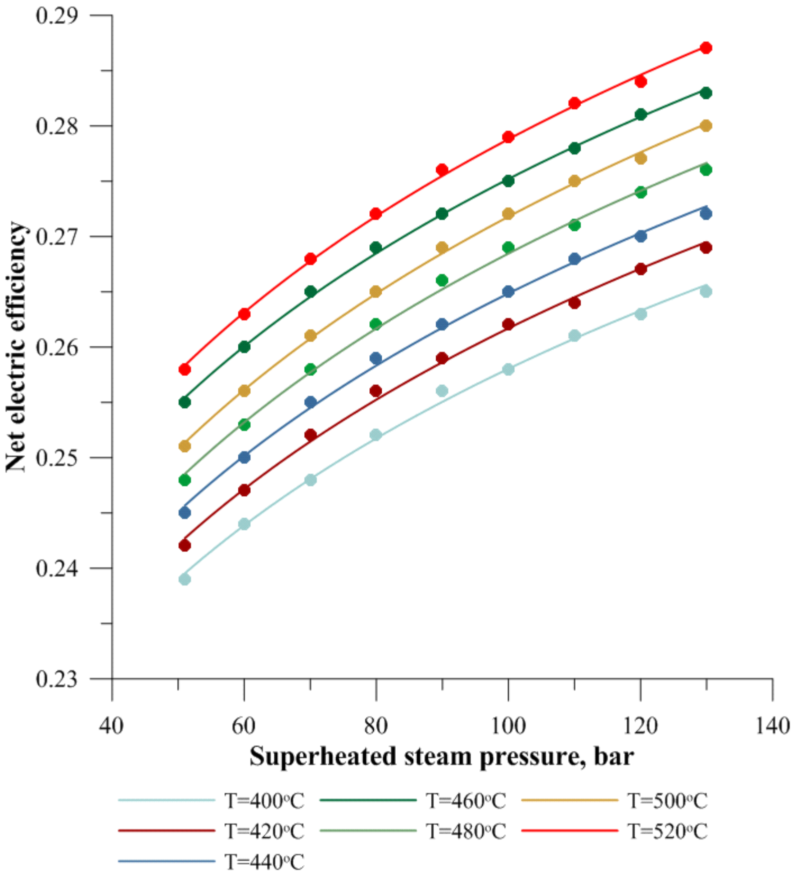
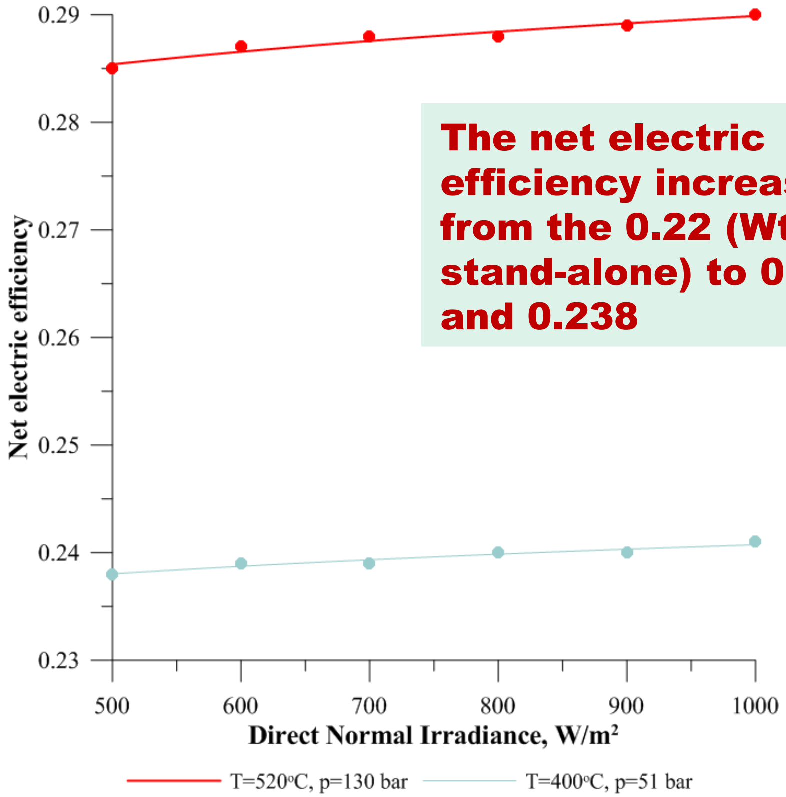


Fig.5 Net electrical efficiency as a function of temperature and pressure of superheated steam (DNI=600 W/m²)



The net electric efficiency increases from the 0.22 (WtE stand-alone) to 0.290 and 0.238

Fig.6 Net electrical efficiency as a function of direct normal irradiance

Results – economic analysis

T=400°C, p=51 bar, the total investment cost of WtE part is about 7% higher compared to the stand-alone WtE plant

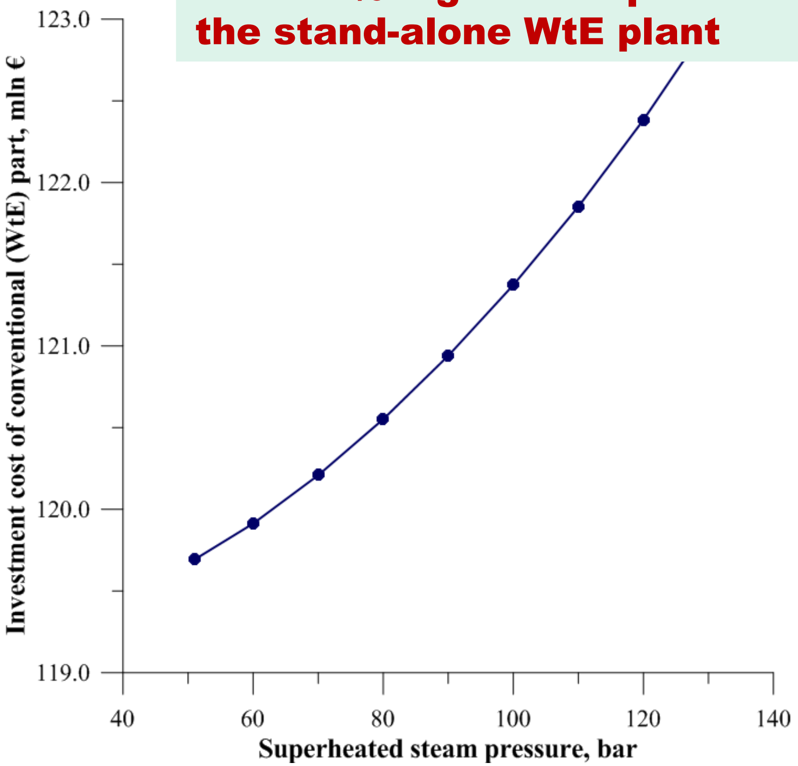


Fig.7 Investment cost of WtE part as a function of temperature and pressure of superheated steam (DNI=600 W/m²)

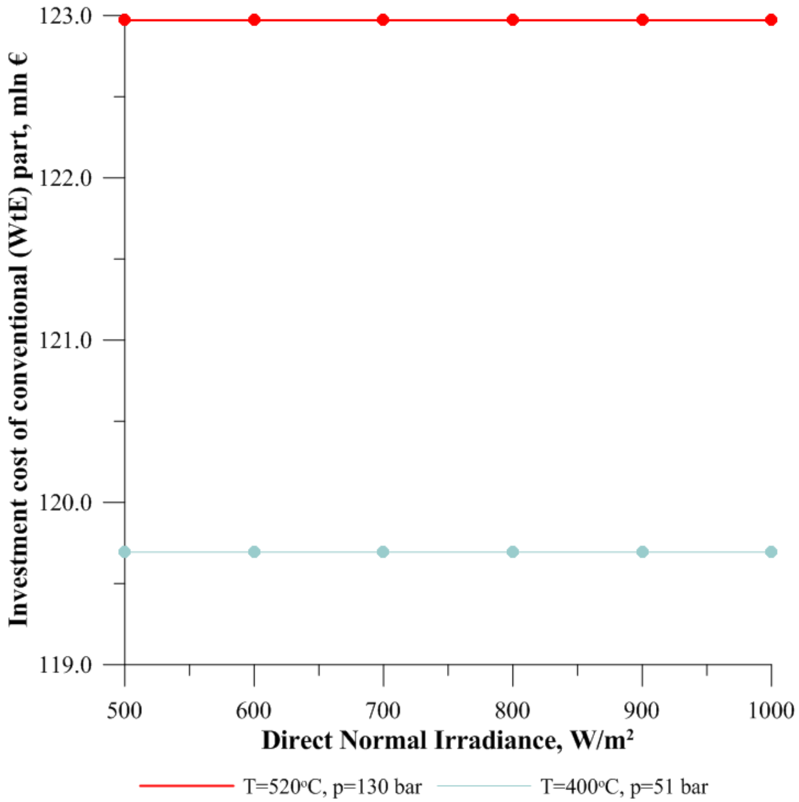
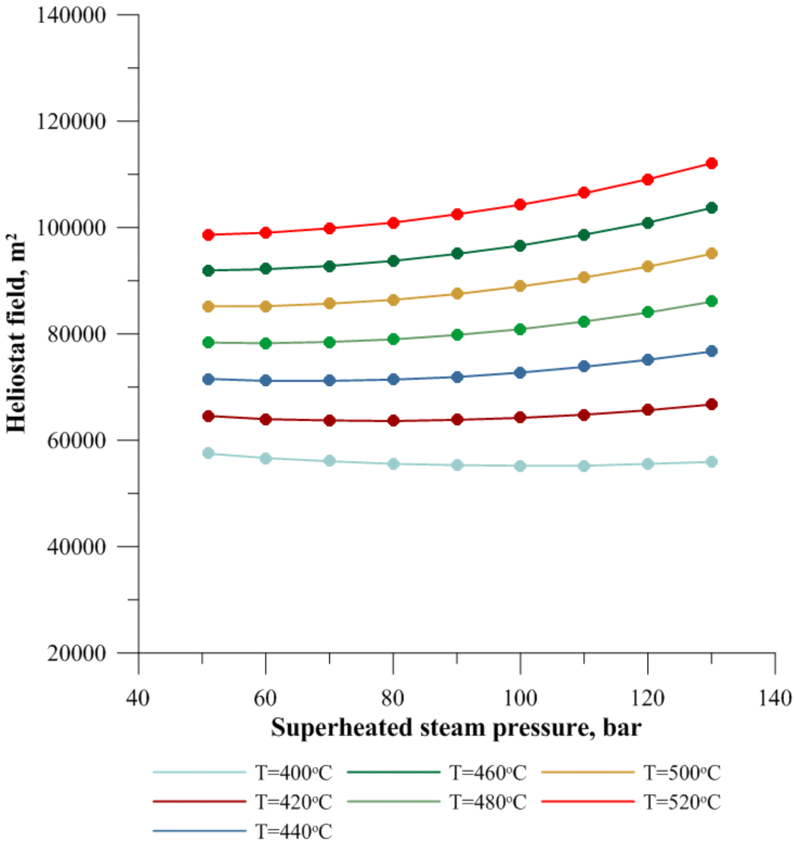


Fig.8 Investment cost of WtE part as a function of direct normal irradiance

Results – economic analysis



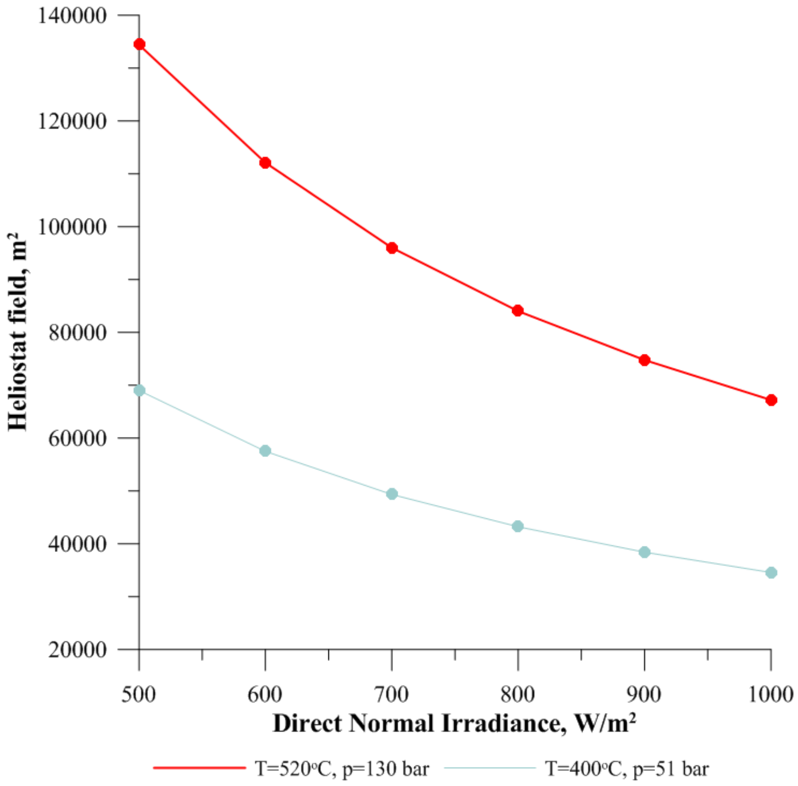
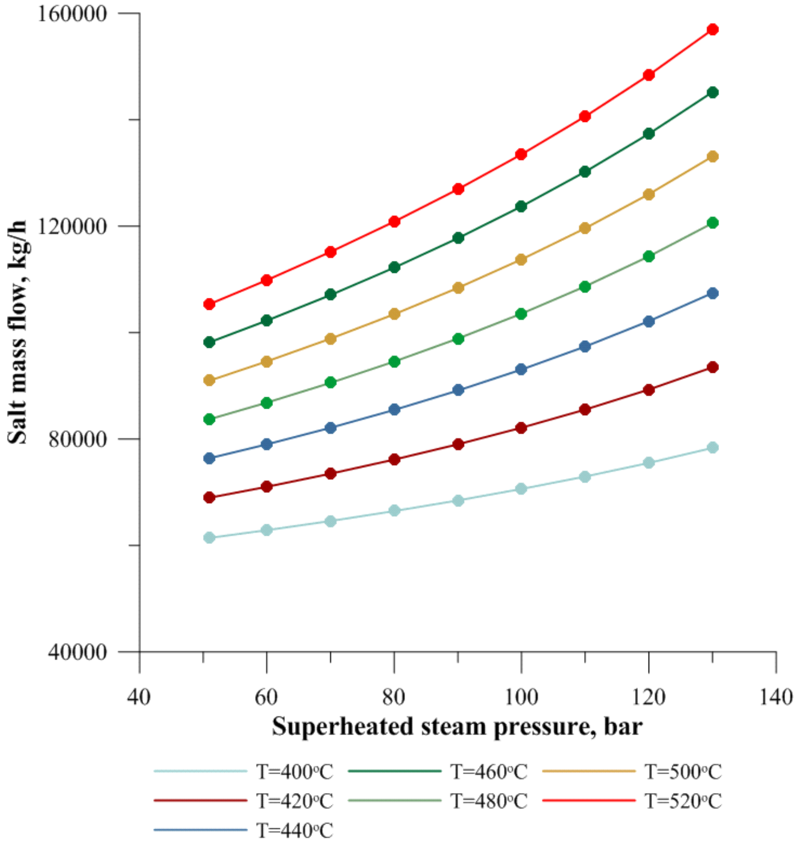


Fig.9 Heliostat field as a function of temperature and pressure of superheated steam (DNI=600 W/m²)

Fig.10 Heliostat field as a function of direct normal irradiance

Results – economic analysis



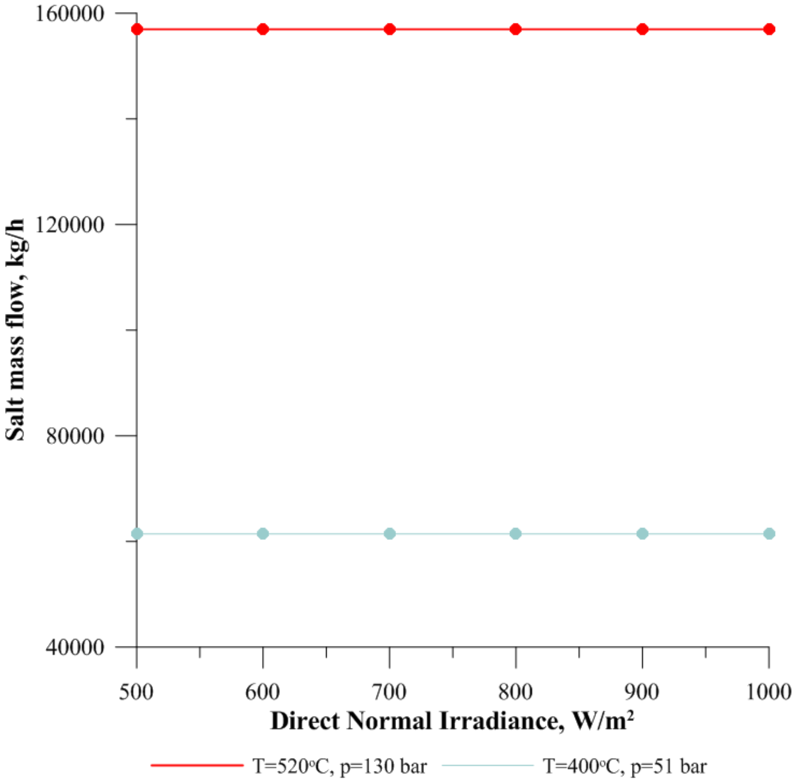


Fig.13 Molten salt mass flow as a function of temperature and pressure of superheated steam (DNI=600 W/m²)

Fig.14 Molten salt mass flow as a function of direct normal irradiance

Results – economic analysis

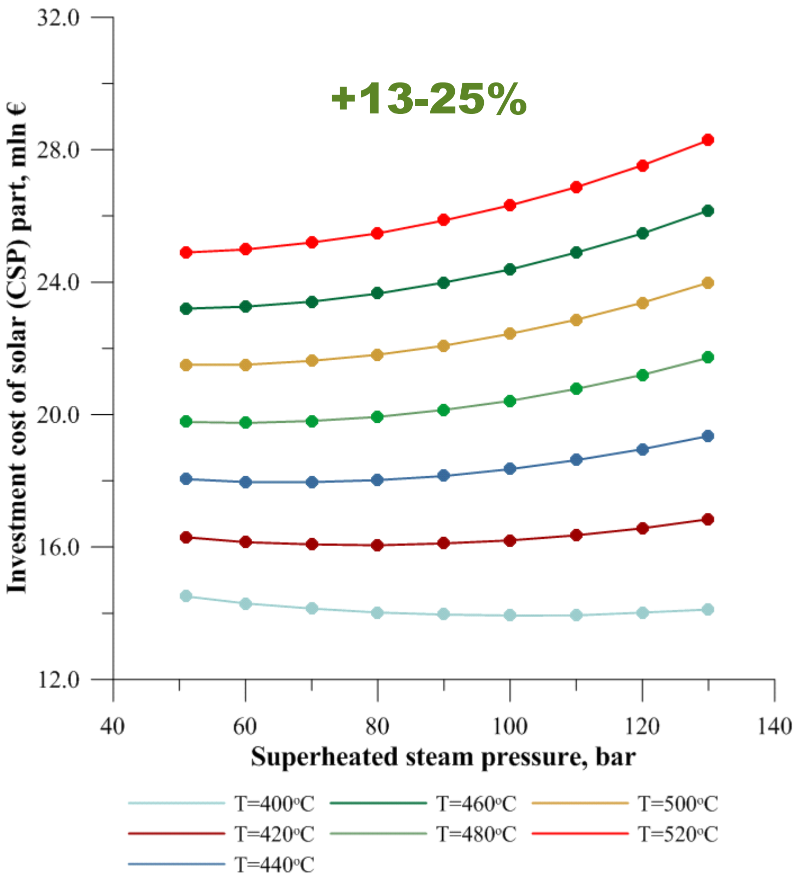


Fig.15 Investment cost of solar part as a function of temperature and pressure of superheated steam (DNI=600 W/m²)

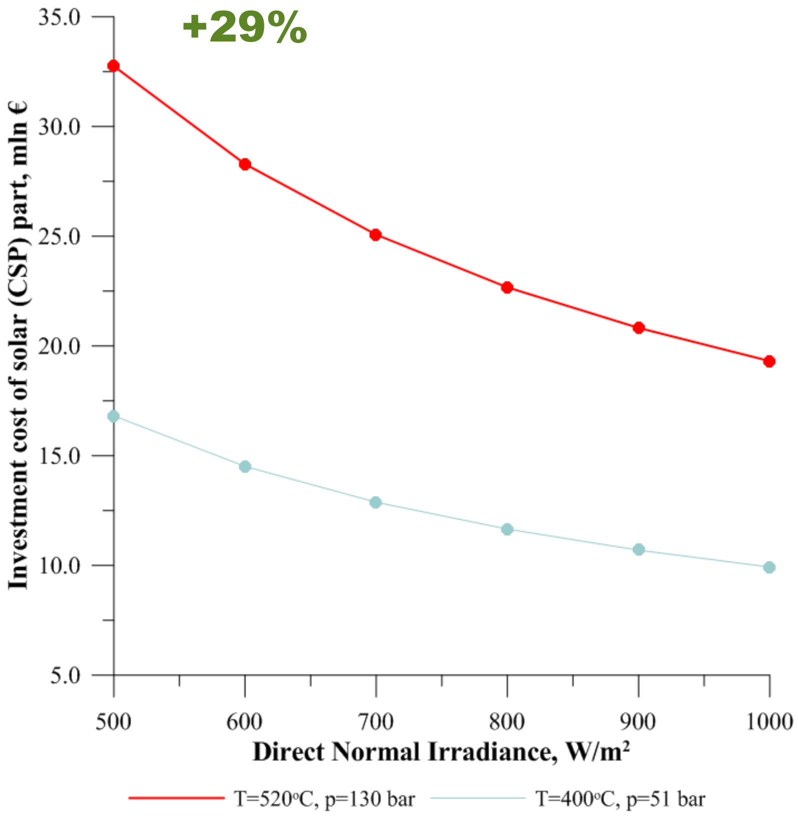


Fig.16 Investment cost of solar part as a function of direct normal irradiance

Results – economic analysis

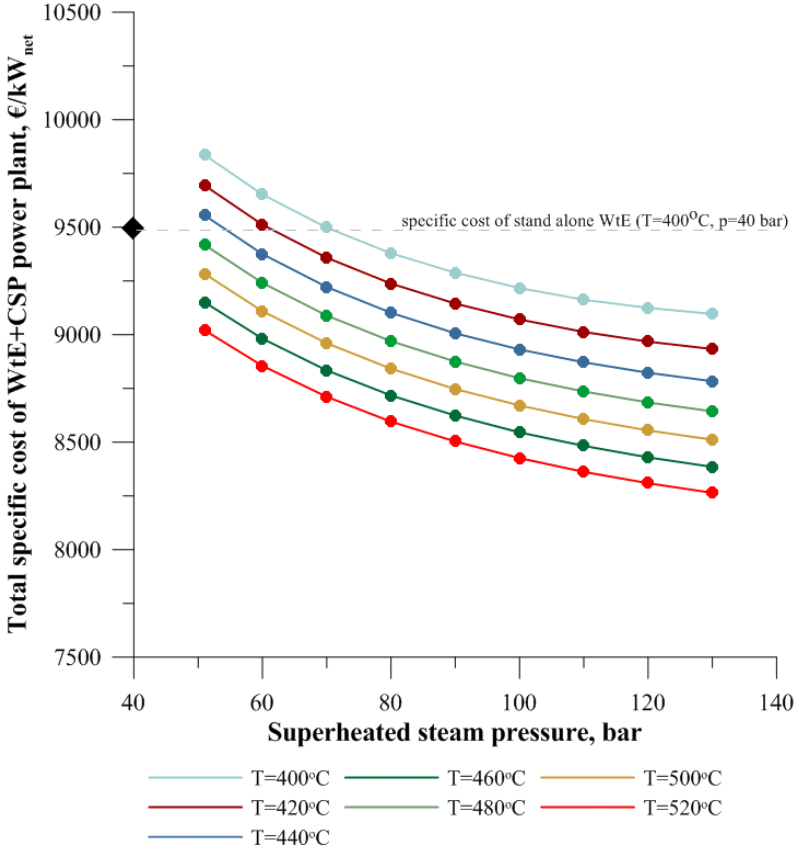


Fig.17 Specific cost of WtE+CSP plant as a function of temperature and pressure of superheated steam (DNI=600 W/m²)

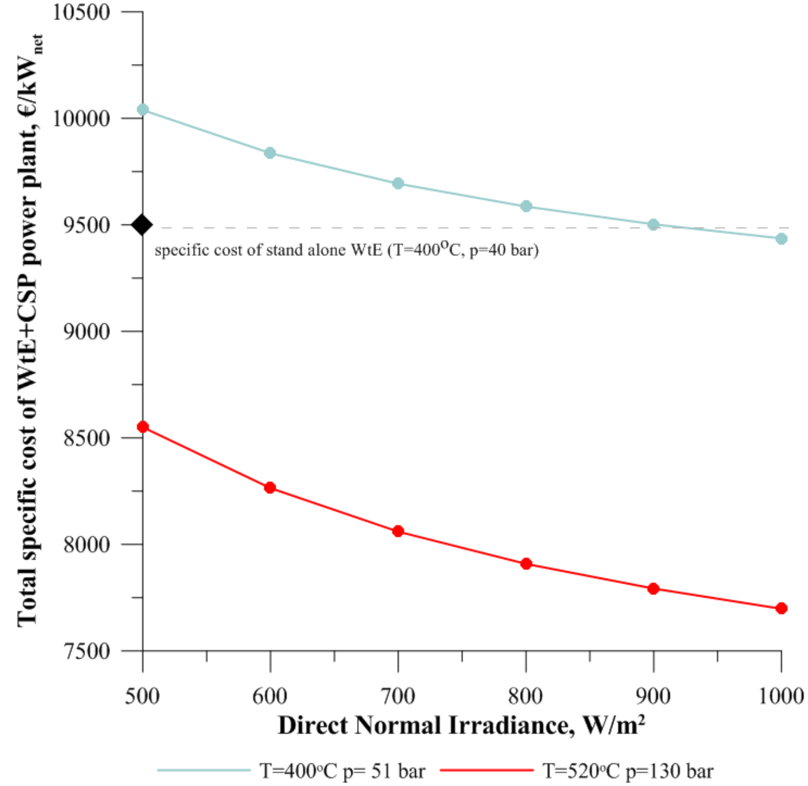


Fig.18 Specific cost of WtE+CSP plant as a function of direct normal irradiance

Conclusions

- **CSP technology holds significant promise for extending and developing of the WtE systems.**

- **Thermodynamic analysis:.** compared to the stand-alone WtE cycle, the integrated WtE+CSP can achieve from 2 to 3 better efficiency points, for the lowest process design parameters depending on the DNI conditions (up to 7.5 efficiency points!).

- **Economic analysis:** the solar part of the plant increases the total investment cost significantly (13-25%, up to 29% for low DNI), however, the increase obtained in the net power production can economically justify the proposed integration (specific cost is reduced!).

- **Further improvements:** the model needs to be developed in order to optimize the process and to allow to perform the dynamic economic analysis of the operational part. Moreover, even if the preliminary economic analysis revealed the viability of the solar power implementation to the WtE, the system should be evaluated from the environmental profits point of view.

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Thank you!

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