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Assessment of Small-Scale Parabolic Trough Collectors for Integration in Industrial Process Heat

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Abstract. This study deals with the preliminary analysis of a small-scale Parabolic Trough Collector (PTC) installed on a rooftop at an industrial complex for the production of process heat. Four scenarios, featuring Heat Transfer Fluid (HTF) outlet temperatures from the PTC of 120°C, 150°C, 200°C, and 250°C, were assessed, varying both collector surfaces and storage capacities; the Levelized Cost of Heat (LCOH) was evaluated for each configuration. The analysis considered data from a commercially available PTC, selected based on a survey among research and industrial partners, and integrated into the System Advisor Model (SAM) libraries. Meteorological data from a North Italian site, characterized by a low annual DNI value, was also considered, assuming this location for the solar plant installation. Economic evaluations employed both literature reviews and real-component purchase price assessments conducted by the partnership. The findings suggest that a LCOH between 4.30 and 4.83 c€/kWh is achievable, with the HTF outlet PTC temperature of 200°C emerging as the scenario allowing for the lowest LCOH due to its balance between the costs of the plant, particularly those related to storage systems, and the thermal energy output.

Keywords: Small-Scale Parabolic Trough Collector, Industrial Process Heat, Levelized Cost of Heat

1. Introduction

Final energy for heating and cooling accounts for almost half of the total energy consumption in Europe, 30% of which is used by the industrial sector. The dialogue between research and industry has highlighted the need for efficient process heat generation in the thermo-mechanical sector to reduce the energy required for low- to medium-temperature services [1]. Brembana&Rolle is an energy intensive industrial user, operating in thermomechanical sector, whose workshops are sited in North of Italy; heat is utilized at low-to-high temperature level, i.e. from ambient temperature to 600-800 °C on continuous daily basis. Adoption of renewable based solution is estimated worth in reducing consumption of valuable fuels (today methane, tomorrow e.g. hydrogen) for low-to-medium temperature requirements. Renewable energy technologies, such as solar energy, which can be modular and standardized for easy implementation on industrial rooftops, can also generate heat for industrial processes [2]. Small-scale Parabolic Trough Collectors (PTC) integrated with Thermal Energy Storage (TES) systems are particularly promising, allowing for flexible energy production while aiming to maintain a Levelized Cost of Heat (LCOH) aligned with European strategies to cut emissions [3]. This technology also avoids transport and conversion losses and allows heat to be produced locally for direct integration into industrial processes. Additionally, the integration of TES systems into Concentrating Solar Power (CSP) plants in recent years has led to an increase in capacity factor and greater flexibility in energy dispatch, contributing to a decrease in the Levelized Cost of Electricity (LCOE). The same can be expected for the LCOH [4]. This study focuses on temperature ranges between 120°C and 250°C [5] and analyses the integration of a small-scale commercial PTC into an industrial context, evaluating the LCOH in order to assess a preliminary feasibility and provide introductory data for future investigations on CSP process heat. An overview of potential applications is presented and discussed in the context of the Italian national industrial framework. The structure of the paper is outlined as follows: Section 2 presents the methodology, details the plant and its key components, describes the approach for conducting the numerical simulations, and the economic analysis. Section 3 reports the outcomes of both the simulations and the economic analysis. Finally, Section 4 concludes with a summary of the main findings and outlines future directions for this research.

2. Material and Method

2.1 Power plant description

Figure 1 depicts the integrated plant layout, which includes a small-scale PTC, a dual-tank TES system (hot and cold), and the links to the industrial process. The path of the hot Heat Transfer Fluid (HTF) is shown in red, the cold HTF in blue, while the connection from the hot tank to the process is represented in yellow. The HTF flows through the solar field, where it is heated and can either move to the TES or directly to the industrial process. Therminol 66 was selected as both the HTF and the storage medium due to its high-temperature thermal stability and its ability to be pumped at low temperatures [6][7], allowing it to be used directly for heat release in the industrial process without the need for intermediate storage media. Furthermore, its operating temperature range (0-345°C) is compatible with the temperatures required by the industrial process.

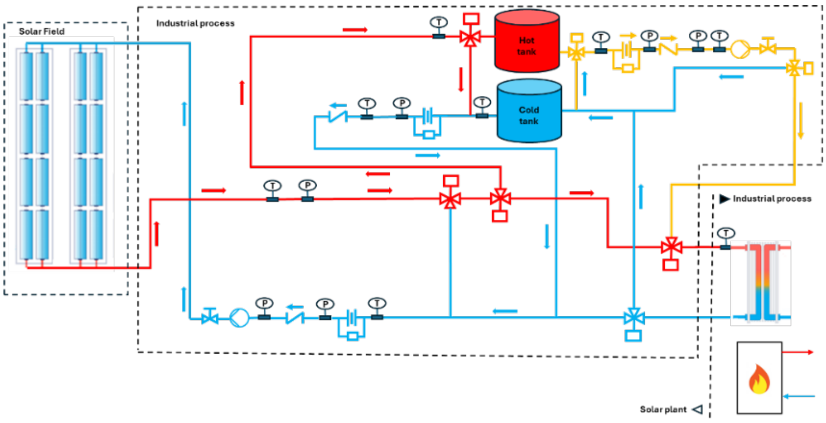

Figure 1. *Industrial process and CSP-TES integrated layout.*

The industrial process analysed features a peak thermal power capacity of 300 kW_{th}, does not include any integration with fossil fuels, and requires the preheating of the HTF from ambient temperature. For the design of the solar field and the TES system capacity, four HTF outlet temperatures from the collector ($T_{PTC,out}$) were considered: 120°C, 150°C, 200°C, and 250°C. It is assumed that the PTC system will be installed on the rooftop, which has an available surface area of 2000 m^2. The dimensions of each loop were calculated by the software based on the Solar Multiple (SM) and the selected $T_{PTC,out}$. Considerations regarding the permissible weight load of the structure have not been addressed at this stage. The PTC considered in this study is a small-scale model selected based on a preliminary survey conducted with research and industrial partners in the Italian CSP market. Under design conditions, the system has an optical efficiency of 71%, incorporates a mono-axial tracking system, and has a potential lifespan of over 20 years.

Table 1 lists the main parameters of the receiver and the collector of the PTC under consideration [8], while Figure 2 illustrates the trend of the longitudinal Incidence Angle Modifier (IAM) as a function of the angle of incidence [9]. Under design conditions, the system has an optical efficiency of 71%, incorporates a mono-axial tracking system, and has a potential lifespan of over 20 years.

Table 1. *Main parameter of the small-scale PTC considered [8]*

Item	Value
Aperture area [m^2]	8.25
Aperture width total structure [m]	1.2
Length of collector assembly [m]	8.24
Average surface to focus path length [m]	0.15
Tracking error [-]	0.99
Geometry effects [-]	0.9
Mirror reflectance [-]	0.93
Average mass flow rate (Therminol 66) [kg/s]	0.288
Absorber tube inner diameter [m]	0.0208
Absorber tube outer diameter [m]	0.022
Glass envelope inner diameter [m]	0.04
Glass envelope outer diameter [m]	0.042
Internal surface roughness [-]	0.000144231
Annulus pressure [torr]	760
Material type [-]	Stainless steel
Heat loss @ 120°C;150°C;200°C;250°C [W/m]	33.29;43.80;61.32;78.85

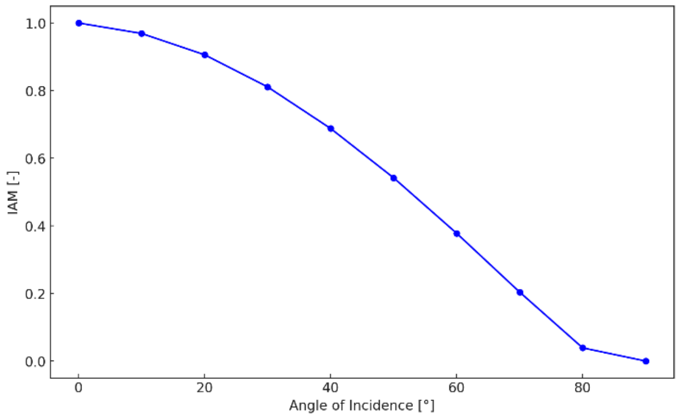

Figure 2. *Incidence Angle Modifier as a function of the angle of incidence [9].*

2.2 PTC Plant Simulations

For the CSP plant simulation, System Advisory Model (SAM) software [10] was employed, using the “No Financial Model” of the Parabolic Trough in the Industrial Process Heat path. Commercial PTC data, such as dimensions, IAM, and heat losses, were implemented in the collectors’ and receivers’ libraries. Meteorological data for the Bergamo site (45.73°, 9.63°), located in northern Italy, were extracted from the National Solar Radiation Database of NREL [11] and incorporated into the solar resource path. In the “design point parameters” interface display, the heat sink power (0.3 MW_{th}), the loop inlet HTF temperature (25°C), and the loop outlet HTF temperature for each considered $T_{PTC,out}$ were indicated. The design point Direct Normal Irradiance (DNI) was set at 880 W/m^2, as it corresponds to the 95th percentile of the cumulative distribution function of the DNI at the considered site (annual DNI of 1430 kWh/m^2). Therminol 66 was selected in the solar field and storage system parameters to serve as both the HTF and storage medium. Minimum and maximum single loop flow rates were set at 0.28 kg/s and 0.3 kg/s, respectively [9], while the minimum and maximum flow velocities for the header were estimated to be 0.84 m/s and 1 m/s. Regarding the Thermal Storage interface display, it was assumed that the TES is empty at the beginning of the simulations. The cold tank heater set point was set to ambient temperature, while the hot tank heater set point was matched to the $T_{PTC,out}$. It was assumed that the storage tank has a height of five meters and that the HTF can bypass the TES and flow directly to the cycle. Finally, parasitic losses associated with the balance of plant and auxiliary heater, as well as losses in system availability, were neglected. Simulations were then conducted using the “Parametrics” tool, with the SM varied from 1.1 to 1.9 and storage hours from 1 to 12 (as they are compatible with the industrial production cycle), enabling the calculation of both the hourly thermal power of the heat sink and the total energy produced.

2.3 Economic Analysis

The economic analysis was conducted using an in-house tool. The purpose of this analysis was to evaluate the LCOH for different SM (i.e. aperture area) and storage capacity, for each of the analysed $T_{PTC,out}$. The following equation was used for the calculation of the LCOH:

$$LCOH = \frac{I_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \qquad (1)$$

Here, I_0 is the initial investment cost, C_t are the O&M costs, composed of a fixed part (1.5% of the total investment costs) and a variable part equal to 0.09 c€/kWh [12]. T is the analysis period, set at 25 years; r is the discount rate (3%); and E_t is the reference thermal energy produced by the plant. Table 2 lists the main cost items assumed for the economic analysis. Direct costs account for the solar field, the HTF, and the double tank system, while indirect costs account for contingency, Engineering, Procurement, and Construction (EPC), and installation costs as a percentage of the direct costs. The sum of direct and indirect costs is I_0. The specific costs of solar collectors and HTF were determined based on the practical experience of industrial and research partners, following an analysis of component acquisition price. In particular, the cost of the solar field includes the piping system, while the total cost of the HTF accounts for the mass contained in the storage volume, in the receiver tube, and in the connections. To estimate the costs of storage tanks and related equipment, an equation was developed that extrapolates the 2014 costs cited in Ref. [13], updated by a scaling factor of 1.38 according to the parameters listed in Ref.[14], to reflect the 2024 costs. Figure 3 shows the trend of storage tank costs as a function of volume for capacities ranging from 2 to 80 m^3.

Table 2. *Cost items of the small-scale PTC power plant.*

Item	Value	Reference
Solar field cost [€/m^2]	120	-
HTF cost [€/kg]	5	-
Tank cost [k€]	$3.6611 \cdot V^{0.5697}$	[13] [14]
Installation costs [%]	24.75	[12]
EPC [%]	11	[15]
Contingency	7	[15]

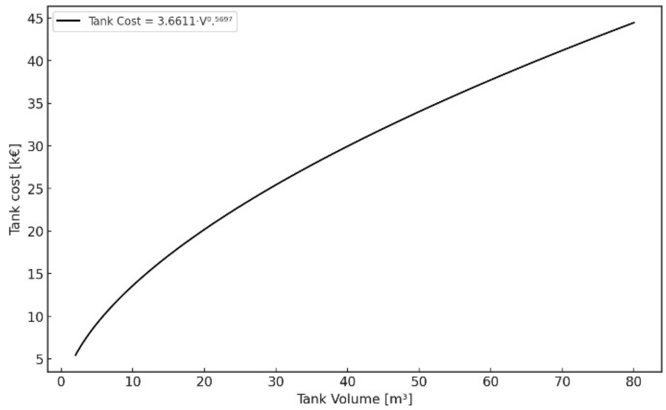

Figure 3. *Trend of costs for small-size vertical storage tanks with cone top & bottom [13][14].*

3. Results

Figure 4 illustrates the energy production derived from simulations conducted using the SAM software, showing the results for the plant layouts in terms of reflective surfaces, as described in the cases listed in Table 3, while considering different hours of energy storage. In turn, Table 3 provides detailed data on the configurations that yielded the lowest LCOH compared to the others examined. Table 3 includes the LCOH value, the total surface area of the solar field, the hours of thermal energy storage, the volume of each storage tank, and the energy generated at each $T_{PTC,out}$ value. Finally, Figure 5 shows the cost trend for the dual-tank system, both hot and cold, as a function of the number of storage hours for each considered $T_{PTC,out}$.

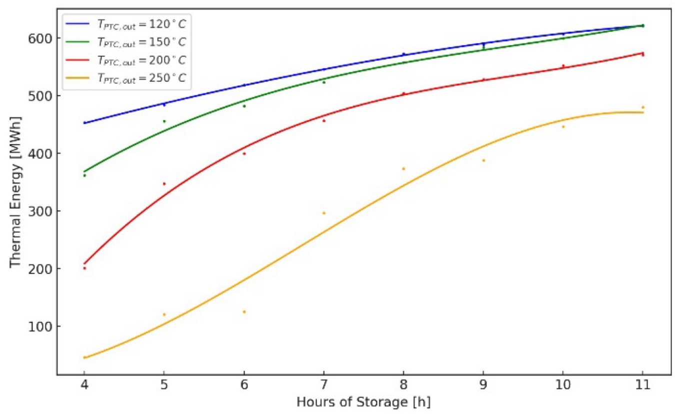

Figure 4. *Thermal energy produced for the selected configurations.*

Table 3. *Layout data of small-scale PTC plants with the lowest LCOH, evaluated across all configurations for the four analysed scenarios.*

$T_{PTC,out}$ [°C]	LCOH [c€/kWh]	Total field area [m²]	Hours of Storage [h]	Single-tank volume [m³]	Energy produced [MWh]	Capacity factor [%]
120	4.40	660	4	25.40	453.10	17.2
150	4.34	693	5	24.26	460.62	17.5
200	4.30	726	8	27.98	504.02	19.2
250	4.83	858	11	30.20	479.64	18.3

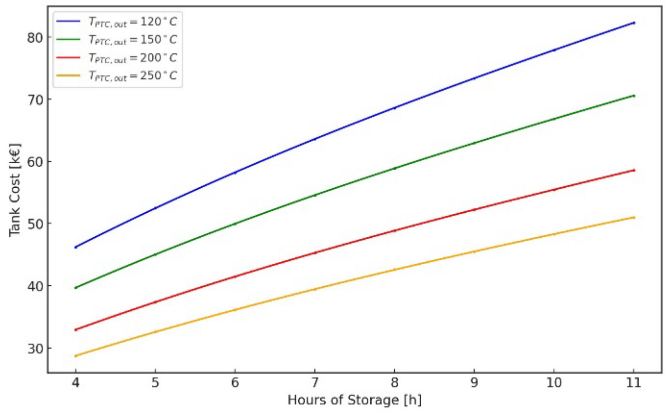

Figure 5. *Cost trend of the dual-tank storage system across different storage durations.*

Table 3 analysis reveals that the LCOH ranged from 4.30 to 4.83 c€/kWh. The lowest LCOH value was consistently achieved with a SM of 1.1 across all examined scenarios but with different storage capacities. It is also necessary to recognize that the hours of storage correspond to different TES volumes for the considered $T_{PTC,out}$, as they are proportional to the temperature difference between the ambient condition, set at 25°C, and the HTF temperature at the collector outlet. Among the four $T_{PTC,out}$ evaluated scenarios, the lowest LCOH of 4.30 c€/kWh was achieved at 200°C. This was attained with a solar field surface area of 726 m^2 and a storage volume of approximately 28 m^3 in a single tank, equivalent to 8 hours of storage. The primary reason is that at 200°C, although the energy production is generally lower than at $T_{PTC,out}$ of 120°C and 150°C (as depicted by the blue and green trends, respectively, in Figure 4), the costs associated with storage tanks are also reduced, as illustrated by the red line trend in Figure 5. For instance, an 8-hour TES layout at 200°C incurs a cost of 48.9 k€ for the dual-tank system; for the same capacity at 120°C, the cost is 68.6 k€, while at 150°C, it amounts to 58.9 k€. Hence, in scenarios at 120°C and 150°C, it is evident that despite generating more energy, the storage costs are higher. In these cases, when compared with the 200°C scenario featuring 8 hours of TES, lower costs are recorded only with 4 and 5 hours of storage, totalling 46.2 k€ and 45.04 k€ for the examined configurations. However, this is accompanied by a consequent decrease in energy generation, with a production equal to 453.10 MWh and 460.62 MWh. Consequently, this results in a LCOH of 4.40 c€/kWh and 4.34 c€/kWh, respectively. Finally, in the scenario with $T_{PTC,out}$ of 250°C, as represented by the yellow line in Figure 4 and Figure 5, the reduced storage system costs do not compensate for the lower energy production associated with the specific type of collector assumed, resulting in a LCOH of 4.83 c€/kWh.

4. Conclusions

In this study, a preliminary investigation was conducted on a small-scale PTC suitable for installation on the approximately 2000 m^2 rooftop of an industrial complex for process heat production. Four scenarios, involving HTF outlet temperatures from the PTC of 120°C, 150°C, 200°C, and 250°C, with different collector surfaces and storage capacities, were considered, and the LCOH for each layout was evaluated. Data from a commercially available small-scale PTC, chosen based on a preliminary survey among research and industrial partners, were implemented into the SAM libraries to perform the CSP plant simulation. Additionally, meteorological data from a North Italian site with a low value of the annual direct normal irradiance, where the solar plant was presumed to be installed, were assumed. The economic analysis reflected both costs from literature and those assessed by the partnership based on the actual purchase prices of components. Preliminary results indicated that it is possible to achieve a LCOH ranging between 4.30 and 4.83 c€/kWh, and that the HTF outlet PTC temperature of 200°C enables the lowest LCOH, as it represents a trade-off between plant costs, particularly those related to storage systems, and the thermal energy produced. Whereas identified solution is compared with baseline alternate, i.e. the actual carbon dioxide compensated fuel supply contract the User is provisioning from local Utility, comparison of LCOH and fuel supply price (around 9.0 c€/kWh ± 15%) confirms advantage of local generation of low-to-medium temperature heat. Albeit price of fuel (actually methane) has been recently subject to structural increase, projected price of new carbon-free fuels is not likely to be lower. Reports from leading consultancy set price of green hydrogen in Europe at 2050 around 2.0-2.5 times more respect to current price of methane, by suggesting its preferential use for electrical generation [16]. Further work will involve evaluating the proposed system at sites with higher annual DNI value and comparing it with small-scale PTC systems currently under development.

Author contributions

F.R. Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. ***W.G.*** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – review & editing. ***F.G.*** Conceptualization, Data curation, Formal analysis, Resources, Validation. ***M.R.*** Conceptualization, Data curation, Formal analysis, Resources, Validation. ***L.N.*** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Writing – review & editing. ***M.D.L.*** Investigation, Methodology, Supervision, Writing – review & editing. ***M.S***. Investigation, Methodology, Software, Validation, Writing – review & editing. ***F.C.*** Investigation, Data curation, Visualization, Writing – original draft.

Competing interests

The authors declare that they have no competing interests.

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References

[1] EUROPEAN COMMISSION DIRECTORATE-GENERAL FOR ENERGY Directorate C. 2-New energy technologies, innovation and clean coal n.d.

[2] Renewables 2023 – Analysis - IEA n.d. https://www.iea.org/reports/renewables-2023 (accessed September 5, 2024).

[3] Union PO of the E. Renewable heating and cooling pathways : towards full decarbonisation by 2050 : final report. 2023. https://doi.org/10.2833/036342.

[4] IRNEA. IRENA (2022), Renewable Power Generation Costs in 2021, International Renewable Energy Agency, Abu Dhabi. ISBN 978-92-9260-452-3. Int Renew Energy Agency 2022:160.

[5] Rehfeldt M, Rohde C, Fleiter T, Toro F, Reitze F. A bottom-up estimation of heating and cooling demand in the European industry n.d.

[6] Grirate H, Zari N, Elmchaouri A, Molina S, Couturier R. Life time analysis of thermal oil used as heat transfer fluid in CSP power plant. AIP Conf Proc 2016;1734. https://doi.org/10.1063/1.4949096.

[7] Ravi Kumar K, Krishna Chaitanya NVV, Sendhil Kumar N. Solar thermal energy technologies and its applications for process heating and power generation – A review. J Clean Prod 2021;282:125296. https://doi.org/10.1016/J.JCLEPRO.2020.125296.
[8] Trivellienergia. Complete system solutions for industrial applications 2007.
[9] ENEA. DTE-BBC 12610_TRIVELLI - Attestazione DM 16.02.2016 - Conto Termico 2.0 2017.
[10] Blair N, Dobos AP, Freeman J, Neises T, Wagner M, Ferguson T, et al. System advisor model, SAM. NREL Rep No TP-6A20-61019, Natl Renew Energy Lab Golden, CO 2014:13.
[11] NREL. National Solar Radiation Database. Nrel 2021. https://nsrdb.nrel.gov/ (accessed October 10, 2021).
[12] Widyolar B, Jiang L, Bhusal Y, Brinkley J, Winston R. Solar thermal process heating with the external compound parabolic concentrator (XCPC) – 45 m2 experimental array performance, annual generation (kWh/m2-year), and economics. Sol Energy 2021;230:131–50. https://doi.org/10.1016/J.SOLENER.2021.10.027.
[13] Matches' Tank cost - API, horizontal, vertical, cone roof, bottom, flat bottom, round end. n.d. https://www.matche.com/equipcost/Tank.html (accessed August 30, 2024).
[14] Cost Indices – Towering Skills n.d. https://toweringskills.com/financial-analysis/cost-indices/ (accessed September 4, 2024).
[15] Immonen J, Mohammadi K, Powell KM. Simulating a solar parabolic trough collector plant used for industrial process heat using an optimized operating scheme that utilizes flexible heat integration. Sol Energy 2022;236:756–71. https://doi.org/10.1016/J.SOLENER.2022.03.044.
[16] Analysing the future cost of green hydrogen | PwC n.d. https://www.pwc.com/gx/en/issues/esg/the-energy-transition/analysing-future-cost-of-green-hydrogen.html (accessed September 18, 2024).