Techno-economic assessment of solar power tower and solar parabolic dish system in India

Pradipta MANDAL(1), K. S. REDDY(2)

(1)(2)Heat Transfer and Thermal Power Laboratory,
Department of Mechanical Engineering, Indian Institute of Technology, Madras Chennai, 600036

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Abstract: The article presents a techno-economic analysis and comparison between the solar power tower (SPT) and the solar parabolic dish system (PDS) for the Indian city of Jodhpur. Both of these technologies are integrated with the Rankine cycle-based power conversion block. The simulation is run for the power block in *Cycle-Tempo* software. The thermal efficiency is obtained as 32%. With $\eta_{\mathrm{th}} = 32\%$ as the input, the technical and economic analyses are carried out. Four economic parameters Net Present Value (NPV), Benefit-to-cost (B/C ratio), Discounted Payback Period (DPP) and Levelized Electricity Cost (LEC) are used in the study. The NPV for SPT and PDS are 335.89 and 252.66 Cr. Rs. respectively. The B/C ratio obtained for SPT and PDS are 3.59 and 2.63 respectively. The DPP obtained for SPT and PDS are 5.58 and 6.77 year respectively. The LEC achieved for SPT and PDS are 1.89 and 2.30 Rs. / kWh respectively. Finally, the sensitivity analysis considering various important parameters such as direct normal irradiance (DNI), discounted interest rate and per square meter reflector cost is performed. It is found that SPT performs better the PDS, both technologically and economically.

Keywords: Solar power tower; Parabolic dish system; Energy and economic analyses; Viability; Sensitivity analysis

1 Introduction

Energy from the sun is a renewable and sustainable source of power derived from the Sun's radiation. It is abundant, clean, and capable of reducing greenhouse gas emissions, making it a critical component in the transition to a greener energy future. Concentrating Solar Power (CSP) is a solar-to-thermal conversion technology that produces electricity by concentrating sunlight onto a small area using mirrors or lenses. The concentrated light is used to heat a working fluid, which then drives a turbine connected to a generator. CSP systems are particularly suitable for large-scale power generation and are often deployed in regions with high direct normal irradiance (DNI). The solar power tower (SPT) and parabolic dish system (PDS) are the two effective CSP technologies that work on the basis of point-focusing technique.

The commercial applications of SPT and PDS technologies are largely dependent on energy efficiency and economic viability. Franchini *et al.*, 2013 analyzed the cycle performance of the Solar Rankine Cycle and the Integrated Solar Combined Cycle through simulations, incorporating parabolic trough and power tower systems. The annual operational performance of the plants was evaluated hourly for the chosen scenarios. In order to evaluate the technical and economic viability of the solar thermally assisted coal-fired power plants, Suresh *et al.*, 2010 concentrated on the 4-E analysis: energy, exergy, environmental, and economical. A significant reduction of approximately 14–19% in coal consumption is observed when turbine bleed streams to all feedwater heaters, including the deaerator, are replaced with Solar-Aided-Feedwater-Heating in the "fuel conservation mode."

Ravi Kumar and Reddy, 2012 conducted Energy-Exergy-Environment-Economical (4-E) evaluation of solar power plants (standalone) based on line-focusing technologies for capacities that range from 1-50 MW_e. The 50-MWe LFR power plants are estimated to have overall energy and exergy efficiency of 12.17% and 17.21%, respectively. While those for the PTC power plant are 23.16% and 32.76%. A study of techno-economic feasibility of a solar parabolic dish plant having a capacity of 5 $MW_e$was conducted by Reddy and Veershetty, 2013 covering fifty eight locations around India. The lowest levelized electricity cost (LEC) for a standalone solar parabolic dish system power generation plant utilizing the clean development mechanism is determined to be Rs.9.83 ($0.197, with an exchange rate of 1 USD = INR 50) in Indore. Murat Cekirge, 2015 compared parabolic trough collector and power tower on the basis of analytical or quantitative aspects rather than qualitative ones. Key factors such as efficiency, plant area, environmental concerns, molten salt storage, plant costs, the impact of dust accumulation, challenges of humidity, various maintenance and operation expenses, and total amount invested are addressed. Yahya *et al.*, 2024 provided a thorough assessment of heat transfer fluid (HTF) performance in concentrated solar power (CSP) systems, with a specific focus on the Noor I CSP plant in Ouarzazate, Morocco. Simulations were carried out using the SAM software (System Advisor Model) from the NREL (National Renewable Energy Laboratory) to evaluate thermal and economic performance of both traditional and silicone-based HTFs, such as Therminol VP-1, Dowtherm A, Helisol 5A, and Helisol XLP. Alam *et al.*, 2023 offered a comprehensive overview of the key and widely used technologies of the CSP: Parabolic Trough Collector system, Line Fresnel Reflector technology, Parabolic Dish System technology, and lastly, Solar Power Tower technology. It also examines the evolving design trends aimed at improving the thermodynamic and hydraulic and optical performance of these collectors. The performance forecast of concentrated solar power plants combined with cooling energy production was the focus of Ravelli *et al.*, 2018. A typical steam Rankine cycle with a 62.1 MWe capacity serves as the foundation for the plant layout. Two separate solar fields—the Central Receiver System and Parabolic Trough Collector system—provide the heat input. Awan *et al.*, 2020 conducted a comparison based study between solar power tower and solar photovoltaic plants from a design and optimization point of view. It has been shown that solar power tower is better than solar photovoltaic from technological aspects, but the reverse is true from economical aspects. Aseri *et al.*, 2021 calculated capital costs and techno-economics of solar parabolic trough and solar power tower plants considering different cooling conditions of the condenser. Praveenkumar *et al.*, 2022 presented technical as well as economical aspects and identified the environmental challenges in India of concentrating solar power (CSP) technology, in general, while being specific to the solar power tower.

From the review of relevant literatures, it is clear that, although there are a considerable number of research papers that discuss comparison-based study of different CSP technologies, there is insufficient analytical data-driven research that compares two important point-focused systems, namely, solar power tower and solar parabolic dish plants, techno-economically. There are also few studies that discuss the scope of commercialization of SPT and PDS plants pertaining to Indian conditions.

The novelty of the present work is pointed out:

- The SPT and PDS based plants are analyzed technologically (energy aspect) and economically (viability aspect).
- An analytical approach is adopted for the energy analysis of CSP counterpart of both the SPT and PDS. However, the cycle analysis of the power block in the plant is done by the Cycle-Tempo simulation.
- A comprehensive sensitivity analysis is provided to understand the influence of different parameters on the economics of the SPT and PDS plants.
- A direct comparison is made between SPT and PDS plants that shows the viable scope of commercial applications.

2 Overall system description

The selection of the site for the installation of a concentrating solar power (CSP) plant is crucial for its efficiency and overall success. Various factors need to be considered to ensure optimal performance and economic viability. Both the Parabolic Dish System and the Power Tower System offer distinct advantages depending on the scale and requirements of solar power plant. The Parabolic Dish is efficient for small-scale, decentralized power generation and is especially well-suited for locations with high direct sunlight. The Power Tower system, on the other hand, is ideal for large-scale power generation with its ability to store thermal energy, ensuring consistent electricity production even in the absence of sunlight. Each system plays a vital role in advancing solar thermal power generation and contributes to the growing portfolio of renewable energy technologies. Essentially, the solar counterpart replaces the coal-based fossil fuel and acts as a boiler in the steam generation plant and the energy is transferred from solar field (either SPT or PDS) to the power block as shown in **Figure 1**. The rotating turbine is connected to the generator and its mechanical energy is used to turn the generator's rotor, transforming the kinetic energy of the turbine into electrical energy. Then the steam is condensed by passing it through a series of tubes or coils of the condenser where it releases the heat and condenses into water. The condensed water is returned to the receiver for recirculation. The cooling tower is used to dissipate excess heat from the condenser by allowing part of the water to evaporate. The evaporation process cools down the remaining water, which is then recirculated back to the condenser. The deaerator is used in the plant to remove dissolved gases, primarily oxygen and carbon dioxide, from the feedwater.

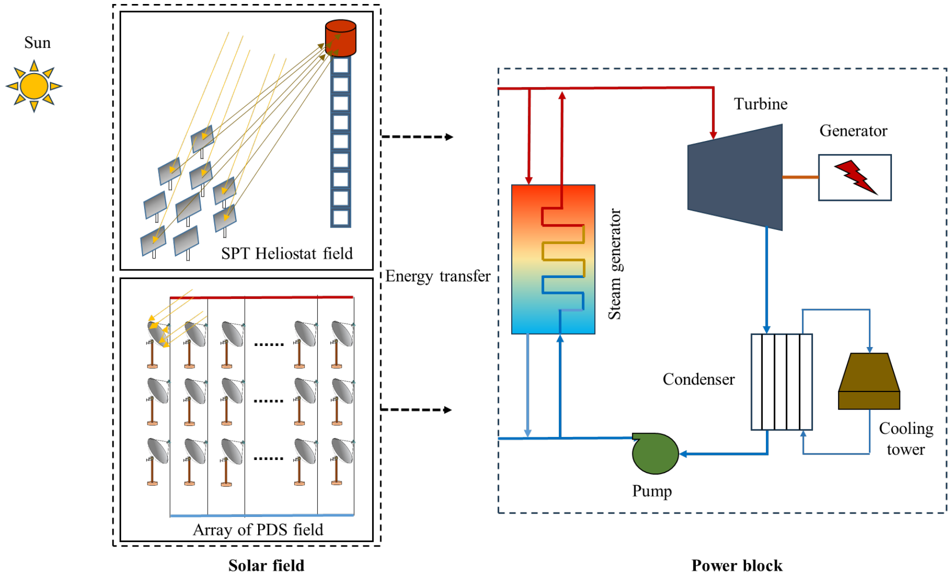


Figure 1: SPT or PDS based solar power plant

Different conditions such as solar resource availability, land availability and topography, environmental impact are crucial for site selection for a CSP plant.

The Indian location of Jodhpur (26.2389°N, 73.0243°E) is chosen as the site for installation of the power plant. This location receives 6.21 kWh/m^2-day average direct normal irradiance (Reddy and Veershetty, 2013). The capacity of the solar thermal power plant is considered 18 MW$_e$ in the present case. The surface area of each reflector for both SPT and PDS is considered to be 120 m^2. The respective assumed parameters for SPT and PDS are summarized in **Table 1** and **Table *2*** respectively.

The summary of the sequential methodology of the present analysis and the associated limitations are described as follows:

- Firstly, the analytical energy analysis of both the SPT and PDS are done considering different respective optical losses for the Indian location of Jodhpur. The equations used for the same are described in the following section.

- Secondly, the power block is simulated in Cycle-Tempo, a flowsheet simulation software used for thermodynamic analysis of the power plant. The data obtained from the previous step are used as input conditions for Cycle-Tempo simulation.

- Based on the data obtained in the previous two steps, an economic study is carried out to determine the comparative viability aspects of SPT and PDS along with necessary sensitivity analysis.

So, in this way, all the three steps are integrated with each other. Therefore, this study gives a detailed view of the technological and economical aspects of SPT and PDS based power plants, which can be used as a first draft to ensure commercial scope in India.

To specify the limitations of this work and possible solutions, the following points should be noted:

- The energy analysis of the solar counterpart is conducted using analytical methodology. An optical simulation can be carried out later to understand the nature of different optical losses that will definitely make the study more accurate.
- The economic input parameters are mostly reference-based, and some data are assumed due to the lack of sufficient information in the literature. The real data of the market price are required for more accurate economic evaluation. Therefore, the data presented here, based on the analysis, should be interpreted accordingly.

3 Energy analysis

For *SPT*, a model used to analyze heliostat field optical efficiency, often seen in academic literature, typically involves multiplying instantaneous optical efficiency factors that account for the optical behavior of heliostat fields. These factors include the cosine effect (η_{cos}), shading and blocking (η_{sb}), spillage (η_{sp}), interception efficiency (η_{int}), atmospheric attenuation (η_{att}), and mirror reflectivity (η_{ref}). The instantaneous field efficiency (η) is given by equation (1) (Yao *et al.*, 2015):

Table 1: Parameters for SPT

Parameters	*Values*
Heliostat reflectivity	88%
Receiver absorptivity	92%
Interception efficiency	98%
Cosine factor	83%
Blocking & shading efficiency	92%
Attenuation efficiency	95%

Table 2: Parameters for PDS

Parameters	*Values*
Dish reflectivity	94%
Receiver absorptivity	94%
Interception efficiency	93%
Piping efficiency	95%
Concentration ratio	1000

$$\eta = \eta_{\cos} \times \eta_{\mathrm{sb}} \times \eta_{\mathrm{sp}} \times \eta_{\mathrm{ref}} \times \eta_{\mathrm{att}} \tag{1}$$

To ensure precise sun-path tracking throughout the day, each heliostat must adjust its orientation based on the incidence angle. The dot product of the incident sunray direction and the mirror's surface normal is used to calculate the cosine efficiency ($\eta_{\cos}$) (Eddhibi et al., 2015):

$$\eta_{\cos} = \overrightarrow{i} \cdot \overrightarrow{n} \tag{2}$$

As reflected rays travel from the mirror-to-receiver, they are influenced by atmospheric attenuation. The distance between the heliostat and the receiver at the top of the tower, as well as specific meteorological factors like visibility, affect the losses brought on by atmospheric attenuation. It is given by (Alizadeh *et al.*, 2020):

$$\eta_{att} = \begin{cases} \exp(-0.00011106 \times d), \\ (\text{for } d > 1000\, m) \\ 0.99321 - 0.000117 \times +1.97 \times 10^{-8} \times d^2, \\ (\text{for } d < 1000\, m) \end{cases} \tag{3}$$

Where, the distance from heliostat to receiver is denoted by *d*.

Here, η_{ref} refers to the quality of the reflective surface, which is influenced by factors such as degradation and cleanliness.

Some of the reflected radiation is lost in transit and does not make it to the receiver. This condition, called spilling (η_{sp}), is caused by tracking precision and mirror quality.

Blocking happens when the backside of the heliostat in front of another obstructs some of the reflected rays, preventing the other heliostat from reflecting its entire surface toward the receiver. Shading, on the other hand, impacts the incident rays, where a heliostat in front casts a shadow on the one behind it. Both of these contribute to η_{sb}.

For PDS, we have to evaluate the concentration ratio.

The optical interception factor for a parabolic dish is expressed by equation

$$\gamma = 1 - exp\left[-\frac{\pi D_r^2}{4\sigma^2}\right] \tag{4}$$

Where, D_r is the diameter of receiver, σ^2 is the variance of beam spread.

For a flat receiver or cavity receiver σ^2 is given by equation

$$\sigma^2 = \frac{2A_a(4\sigma_{\psi 1}^2 + \sigma_{\psi 2}^2)}{(sin\phi)^2} \tag{5}$$

Where, ψ_1 and ψ_2 are slope error and solar beam error, ϕ is the half of the rim angle which is taken as 22.5°.

Assume that the sun's disc has a standard deviation of 0.125° and a mirror surface variance of $(0.25°)^2$, and that the diameter of the parabolic dish is made to accommodate 90% of the incident beam radiation.

The required field area for SPT and PDS system is calculated using energy balance. The SPT or PDS can be integrated with Rankine cycle, Stirling engine and Brayton cycle. For the energy analysis, a power plant based on Rankine cycle is considered. A solar field of SPT or array of PDS is integrated into the Rankine cycle power conversion unit. The solar field is the source of thermal heating. All the components of the power conversion unit are modelled and simulated using flow-sheet program *Cycle-Tempo* (**Figure 2**). The parasitic loss is assumed to be 10 % of the plant nominal capacity. The simulation is conducted to estimate the Rankine cycle efficiency (η_{cycle}), which is used as input for further analysis.

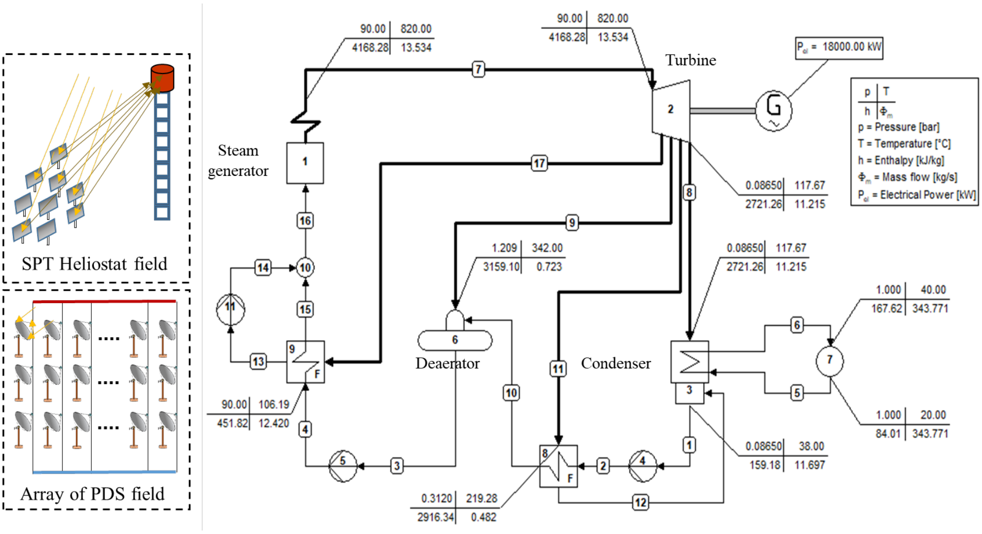


Figure 2: Simulation of power block in Cycle Tempo

Now, utilization of the concentrating solar collector eventually saves the coal cost. The coal cost savings are calculated considering Indian non-coking coal of G-9 grade, the higher heating value (HHV) of which is 20000 kJ/kg (https://coal.gov.in/en/major-statistics/coal-grades).

4 Economic analysis

Constant efforts are being made to replace the coal-based power plant by renewables partially or completely in future. Therefore, in the near future, renewables like solar energy systems will be cheaper than coal (Chakravarty and Somanathan, 2021). So, as for all energy systems, a solar power plant should be economically viable even though it effectively meets the energy needs. Therefore, a rigorous economic analysis is essential.

The important economic component parameters for solar thermal power plants are Net Present Value (NPV), Benefit-to-cost ratio (B/C), Discounted payback period (DPP), Levelized electricity cost (LEC). Usually, either LEC or NPV are used for the viability valuation of the solar-coal thermal power plant.

The capital cost (fixed) as well as the operation and maintenance (O&M) cost of the plant are used to compute all economic metrics. The O&M cost is associated with the administrative work, spare parts of the solar field, equipment, contracts of service, water and labour treatments for the operation and maintenance of the power plant. The following are the economic parameter formulas (Ravi Kumar and Reddy, 2012):

$$LEC = C_{\mathrm{FCap}} + C_{\mathrm{LOM}} \tag{6}$$

Where C_{FCap} is the constant capital cost, C_{LOM} is the cost of levelized operation and maintenance.

The capital cost (fixed) can be defined as:

$$C_{\mathrm{FCap}} = \frac{C_{\mathrm{cap}}}{\mathrm{PG}_{\mathrm{net}}} \tag{7}$$

Where C_{cap} is the capital cost, $\mathrm{PG}_{\mathrm{net}}$ is the net power production.

The $\mathrm{PG}_{\mathrm{net}}$ is given as:

$$\mathrm{PG}_{\mathrm{net}} = \mathrm{PG}_{\mathrm{tot}} - \mathrm{PG}_{\mathrm{aux}} \tag{8}$$

Where the $\mathrm{PG}_{\mathrm{tot}}$ is the total generated power and $\mathrm{PG}_{\mathrm{aux}}$ is the consumption of the auxiliary power which accounts for the dual axes tracking and feed water pumping and the value of $\mathrm{PG}_{\mathrm{aux}}$ is taken in the range of 8-10% of the total power generated.

Levelized O&M cost (C_{LOM}) can be calculated as:

$$C_{\mathrm{LOM}} = LF\ (C_{\mathrm{FOM}} - C_{\mathrm{VOM}}) \tag{9}$$

Where, LF is called the levelizing factor, C_{FOM} is the cost of fixed operation and maintenance and C_{VOM} is the variable operation and maintenance cost.

The LF can be expressed by equation (10):

$$LF = \left[\frac{(1+i_e)^{lt}-1}{\mathrm{dr}_e(1+\mathrm{dr}_e)^{lt}}\right]\left[\frac{dr(1+i)^{lt}}{(1+i)^{lt}-1}\right] \tag{10}$$

Where i is the rate of discount (%), i_e is the equivalent rate of discount (%) considering escalation, lt is the lifetime of the solar power plant.

$$\mathrm{dr}_e = \frac{(dr-e)}{(1+e)} \tag{11}$$

The fixed *O&M* cost is given by equation (12),

$$C_{\mathrm{FOM}} = \frac{C_{\mathrm{OM}}}{\mathrm{PG_{net}}} \tag{12}$$

Moreover, additional O&M cost is included in the variable O&M cost and it is given by equation (13),

$$C_{\mathrm{VOM}} = 0.1\ \mathrm{C_{FOM}} \tag{13}$$

The following equation (14) provides solar power plant's *DPP (year)* as:

$$\frac{B}{C} = \frac{1}{C_{\mathrm{Cap}}}\left[\sum_{j}^{lt}\frac{(B_j-C_j)}{(1+dr)^j}\right] \tag{14}$$

It is anticipated that the investigator will receive a consistent net benefit $(B_j - C_j)$ over the course of the power plant's life.

The following equation (15) provides the system's NPV (Rs.):

$$NPV = \left[\sum_{j}^{lt}\frac{(B_j-C_j)}{(1+dr)^j}\right] - C_{\mathrm{Cap}} \tag{15}$$

All the calculations related to the economics of the power plant have been done using a developed spreadsheet Excel program. The coal cost savings are also accounted for in this study. The price of Indian non-coking coal of G-9 grade is taken to be Rs. 9.2 /kg (https://coal-price.com/). **Table 3** and **Table 4**, respectively, summarize the input parameters taken into account for the current economic calculations of SPT and PDS plants.

Table 3: Economic input parameters for SPT plant

Parameters	*Value/ Unit cost/ Cost function*
Heliostat cost (Rs.)	$5777/\text{m}^2$ (Eicker *et al.*, 1981)
Receiver cost (Rs.)	$A_R\,[79T_{\text{out}} - 42000]$ (Kumar and Kumar, 2022)
Tower cost (Rs.)	$83 \times \left[0.78232 \times 10^6 \times e^{0.0113 \times HT}\right]$ (Mohammadi *et al.*, 2019)
Site preparation and installation cost (Rs.)	$427/\text{m}^2$
O&M cost (Rs.)	15% of annual capital cost
Life of the plant (Year)	30
Discount rate (%)	10
Escalation rate (%)	5

In **Table 3**, A_R denotes the heat absorbing area of the surface of the receiver and T_{out} is the outlet steam temperature which is 560. The cost of heliostat per square meter is taken to be the same as that of a parabolic dish. Moreover, 1$ = Rs. 83 is considered.

For the present analysis, the salvage value of the plant at the end of its life (30 years) is taken to be 20% of the capital investment (Sahu et al., 2021). The reference (Eicker *et al.*, 1981) discusses the comparative cost of solar power tower and solar parabolic dish. Accordingly, a suitable proportionate scale factor has been chosen and adjusted to project the costs of some of the PDS cost components with respect to the solar power tower. The receiver cost, piping cost and support strut and rotary joints cost of PDS are significantly higher than those for SPT (Eicker *et al.*, 1981).

Table 4: Economic input parameters for PDS plant (Sahu *et al.*, 2021)

Parameters	*Value/ Unit cost/ Cost function*
Parabolic dish cost (Rs.)	$6877/\text{m}^2$
O&M cost (Rs.)	15% of the annual capital cost
Land cost (Rs.)	300000/acre
Plant life (Year)	30
Rate of discount (%)	10
Escalation rate (%)	5

The *sensitivity analysis* plays an important role in evaluating the robustness of the economic model. So far, all the energy and cost analyses have been carried out considering a constant value of DNI (W/m^2), a constant value of discounted interest rate (%) and constant reflector cost per square meter (Rs. $/\text{m}^2$).

5 Results and discussion

The plant involves two feedwater heaters for the purpose of preheating the water so that the irreversibility associated with the steam generation can be reduced. The deaerator provides protection to the system from the dissolved corrosive gases. The variation of temperature with transmitted heat in flash heaters and deaerator as well as the temperature-entropy diagram of the cycle are displayed in **Figure 3 (a)** and **Figure 3 (b)** respectively.

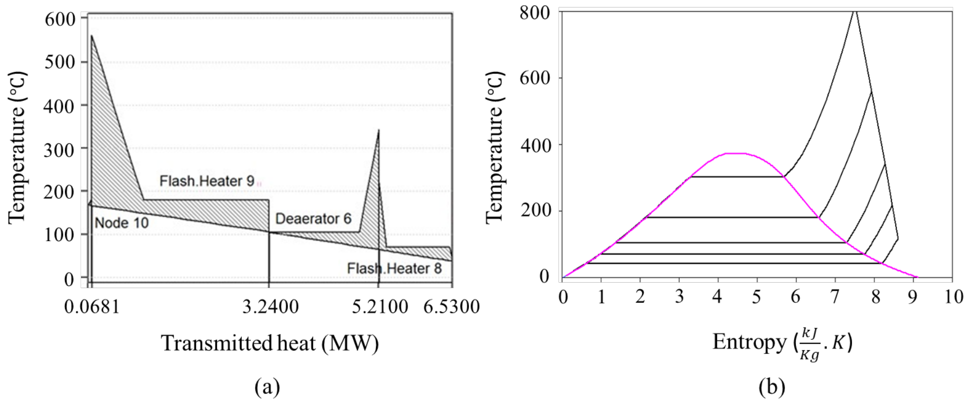


Figure 3: (a) Variation of temperature with transmitted heat ; (b) The temperature-entropy (T-s) diagram of the plant

The mixing process occurs at node 10. After that the steam is superheated. Then, the condensation begins at high pressure feedwater heater (flash heater 9). The same thing happens with the low-pressure feedwater heater (flash heater 8). At the end, 5°C sub-cooling is used. The maximum temperature reached by the steam is around 800°C. An isentropic efficiency of 85% has been considered in the analysis. Using simulation, the cycle efficiency of the power plant is obtained as $\eta_{\text{th}} = 32\%$. The Cycle-Tempo simulation results are tabulated in **Table 5**. This value of thermal efficiency is used for sizing and economic analysis of SPT and PDS.

The solar power tower and solar parabolic dish field analyses have been carried out using the results obtained from simulation as input parameters. The Excel spreadsheet program is prepared for analytical calculations. The solar field analysis requires a number of influential parameters such as reflectivity of the dish reflector, interception efficiency, absorptivity of the receiver.

The solar parabolic dish eventually diminishes the requirement of coal which leads to coal cost savings. The auxiliary consumption is considered 10% of total power generated.

A solar power plant's anticipated residual worth or value at the end of its useful life is referred to as its salvage value. It is essentially the amount that could be obtained by selling the power plant's components, equipment, and other assets after they have reached the end of their operational lifespan. Determining the salvage value is a crucial aspect of financial planning and asset management for power plant owners and operators.

Table 5: Simulated results of the power block

Parameters	Apparatus	Energy (MW)	Efficiency (%)
Absorbed power	Boiler	55	
Delivered power	Generator	18	
Auxiliary power	Pumps	0.17	
Net power	Overall system	17.83	
System efficiency	Overall system		32

The total capital investment for coal each year is taken as three times the plant capacity. For the coal-only power plant, interest rate, depreciation and operating cost are considered as 4%, 5% and 30% respectively. The capital investment is deducted from the total annual cost and the rest of the cost components have been considered.

This study of net present value involves the consideration of coal cost savings. Considering the recent coal scarcity in India and other countries, the coal price may go higher. In that case, it will lead to a significant coal cost savings. For a particular location, a solar power plant can be expressed in terms of either NPV or LEC to determine if it is viable. In the present study, LEC has been chosen as a criterion to make the decision on the installation and comparison of SPT and PDS plant. The cost estimation for installation of both the SPT and PDC is carried out and the results are tabulated in **Table 6**.

Table 6: Results of economic analysis

Serial No.	Parameters	Results Solar Power Tower	 Parabolic Dish System
1.	Land area (Acre)	61.8	67
2.	No. of reflectors	1250	2712
3.	Capital cost (Cr. Rs.)	110.32	134.42
4.	O&M cost (Cr. Rs. / year)	0.96	1.17
5.	Net Present Value (Cr Rs.)	335.89	252.66
6.	Benefit-to-cost ratio (B/C ratio)	3.59	2.63
7.	Discounted Payback Period (Year)	5.58	6.77
8.	Levelized Electricity Cost (Rs. / kWh)	1.89	2.30

The parameters such as direct normal irradiance, (W/m^2), discounted interest rate (%), cost of reflector per square meter are critical and change with time. Also, a tangible asset's cost can be spread out throughout its useful life using the accounting technique known as depreciation. Businesses can use this technique to balance the initial cost of purchasing an asset with the ongoing revenue it brings in. Assets such as machinery, vehicles, buildings, and equipment gradually lose their value or become obsolete, and depreciation reflects this decline in their worth. Therefore, it is necessary to find out what is the impact of the values for a given input parameter on the value of other parameters.

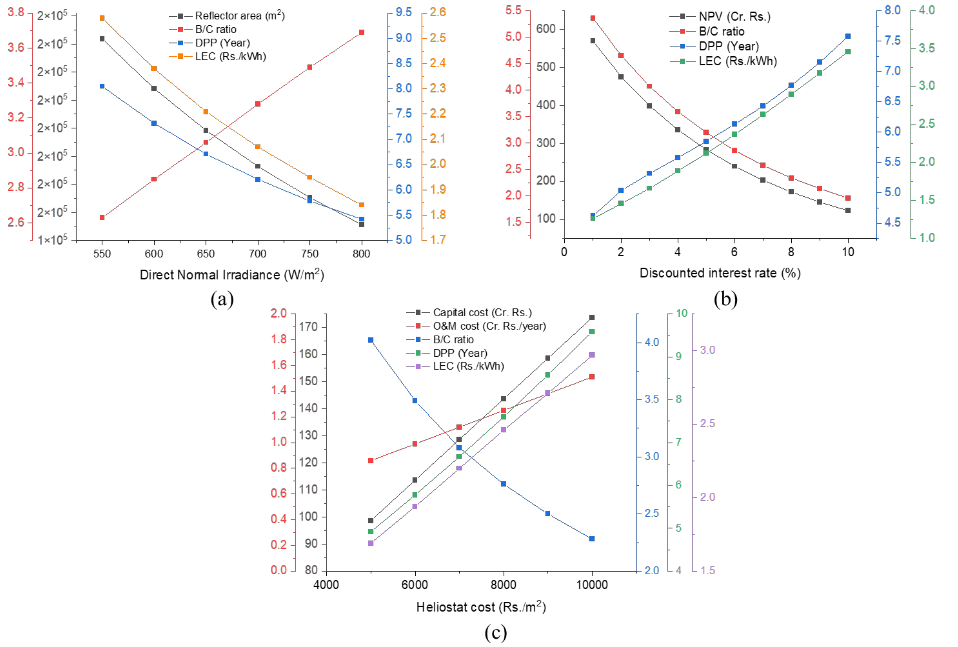
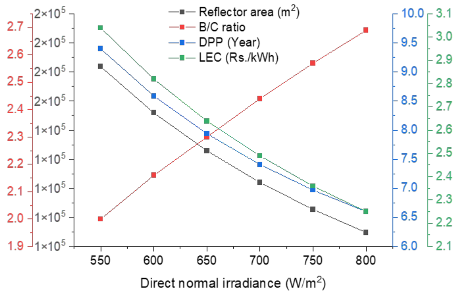


Figure 4: For SPT (a) Variation of reflector area, B/C ratio, DPP and LEC with DNI (b) Variation of NPV, B/C ratio, DPP and LEC with discounted interest rate (c) Variation of capital cost, annual O&M cost, B/C ratio, DPP and LEC with heliostat cost per square meter

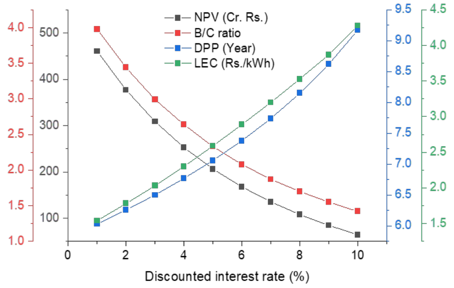
Figure 4 (a) shows the effect of direct normal irradiance (DNI) on total reflector area, benefit-to-cost ratio (B/C), discounted payback period (DPP) and levelized electricity cost (LEC) for SPT plant. The value of DNI is changed from 550 W/m^2 to 800 W/m^2. So, the fact is clear that the reflector area, DPP and LEC reduce with the increase in DNI and B/C ratio decreases with the increase in DNI, which is the expected case. The minimum-maximum values obtained for reflector area, B/C ratio, DPP and LEC are 145597.37 – 211777.99 m^2, 2.63 – 3.69, 5.42 – 8.05 year and 1.84 -2.58 Rs. / kWh.

Figure 4 (b) depicts the effect of equivalent discounted interest rate (i_e) on the net present value (NPV), benefit-to-cost ratio (B/C), discounted payback period (DPP) and levelized electricity cost (LEC) for SPT plant. The value of *ie* is changed from 1% to 10%. As it can be seen, the net present value and B/C ratio decrease with increase in discounted interest rate i_e, while DPP and LEC increase with the increase in i_e, which is the expected case. The minimum-maximum values obtained for NPV, B/C ratio, DPP and LEC are 122.97 – 570 Cr. Rs., 1.96 – 5.36, 1.26 – 3.46 Rs. / kWh.

Figure 4 (c) shows the effect of per square meter cost of heliostat reflector on the capital cost, annual operation and maintenance cost, benefit-to-cost ratio (B/C), discounted payback period (DPP) and levelized electricity cost (LEC). The value of per square meter cost of heliostat is changed from 5000 Rs. /m^2 to 10000 Rs. /m^2. It is apparent that the capital investment, DPP and LEC increase with dish cost, whereas B/C ratio decreases with increase in heliostat cost per square meter. The minimum-maximum values obtained for the capital cost, annual O&M cost, B/C ratio, DPP and LEC are 98.66 - 173.69 Cr. Rs., 0.86 – 1.51 Cr. Rs., 2.28 – 4.02, 4.92 – 9.59 year, 1.69 – 2.97 Rs. / kWh.



(a)



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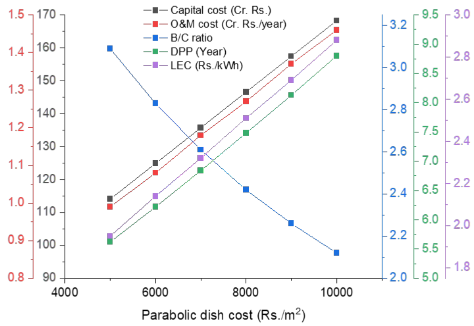

(c)

Figure 5: For PDS (a) Variation of reflector area, B/C ratio, DPP and LEC with DNI (b) Variation of NPV, B/C ratio, DPP and LEC with discounted interest rate (c) Variation of capital cost, annual O&M cost, B/C ratio, DPP and LEC with dish cost per square meter

Similarly, the sensitivity analysis is performed for PDS system. Very similar trends of the variation are achieved for PDS system. When direct normal irradiance varies, the minimum-maximum values obtained for reflector area, B/C ratio, DPP and LEC for the PDS system are 104826.20 – 161875.64 m^2, 2.00 – 2.69, 6.60 – 9.40 year, 2.25 – 3.04 Rs. / kWh. The variations of respective parameters with DNI are plotted in **Figure 5 (a)**.

When discounted interest rate varies, the minimum-maximum values obtained for NPV, B/C ratio, DPP and LEC for the PDS system are 64.45 – 460.79 Cr. Rs., 1.42 – 3.98, 6.03 – 9.17 year, 1.54 – 4.28 Rs. / kWh. The variations of respective parameters with discounted interest rate are plotted in **Figure 5 (b)**.

When the cost of the parabolic dish per square meter varies, the minimum-maximum values obtained for capital cost, annual O&M cost, B/C ratio, DPP and LEC for the PDS system are 114.06 – 168.29 Cr. Rs., 0.99 – 1.46 Cr. Rs., 2.13 – 3.09, 5.62 – 8.80 year, 1.95 – 2.88 Rs. / kWh. The variations of respective parameters with per square meter parabolic dish cost are plotted in **Figure 5 (c).**

The levelized cost obtained in the present study is compared with other published works in **Table 7**. It should be noted that the data must be interpreted carefully since each reference considers different conditions.

Table 7: Comparison with other similar studies

Sl. No.	*Reference*	*Location, Country*	*CSP technology (Rated capacity)*	*Thermal Energy Storage (Hours)*	*Levelized Electricity*
1	Agyekum and Velkin, 2020	Navrongo and Tamale, Ghana	SPT (100 MW_e)	12	13.67 USD cents/kWh
2	Abbas *et al.*, 2011	Algiers, Algeria	PDS (100 MW_e)	-	235 USD/kWh
3	Praveenkumar *et al.*, 2022	Bhopal, India	SPT (100 MW_e)	12	13.22 USD cents/kWh
4	Xu *et al.*, 2022	China	SPT (50 MW_e)	6	0.15 USD/kWh
5	Aly *et al.*, 2019	Dodoma site, Sulunga site, Tanzania	SPT (100 MW_e)	4	11.6-12.5 USD cents/kWh
6	Kamel *et al.*, 2022	Ethiopia	SPT (100 MW_e)	12	9.44 USD cents/kWh
7	Luo *et al.*, 2017	Seville, Spain	SPT (100 MW_e)	3	21 USD cents/kWh
8	Present work	Jodhpur, India	SPT, PDS (18 MW_e)	-	1.89 Rs/kWh for SPT, 2.30 Rs/kWh for PDS

6 Conclusions

A detailed techno-economic assessment of an 18 MW_e power plant utilizing either a solar power tower or a parabolic dish system is provided, along with a comparison to evaluate their feasibility for installation in Jodhpur, India. The energy achieved in the receiver is calculated analytically for respective SPT and PDS considering various optical losses. Then, the calculated data are used as input for power block modeling in Cycle-Tempo. Finally, an economic analysis is carried out by inputting the previously calculated data. The energy modeling of the Rankine cycle power block results in a thermal efficiency of 32%.

- The solar field requirement of SPT and PDS for 18 MW_e plant capacity are 61.8 Acre and 67 Acre respectively.
- The number of reflectors required for SPT and PDS are 1250 and 2712 respectively.
- The necessary capital investment for SPT and PDS are 110.32 and 134.42 Cr. Rs. respectively.
- The annual operation and management cost (O&M) for SPT and PDS are 0.96 and 1.17 Cr. Rs respectively.

- The net present value (NPV) for SPT and PDS are 335.89 and 252.66 Cr. Rs. respectively.
- The benefit-to-cost ratio (B/C) obtained for SPT and PDS are 3.59 and 2.63 respectively.
- The discounted payback period (DPP) obtained for SPT and PDS are 5.58 and 6.77 year respectively.
- The levelized cost of electricity (LEC) achieved for SPT and PDS are1.89 and 2.30 Rs. / kWh respectively.

The sensitivity analysis shows expected similar trends of variation of critical parameters such as direct normal irradiance available at the particular location, discounted interest rate and per square meter reflector cost on techno-economic evaluation of SPT and PDS. The installation of a solar thermal power plant can be considered viable if the levelized electricity cost is less than the levelized tariff. The levelized tariff of solar thermal power generation is Rs. 13.45 (CERC, 2009). In this view,

- Both the solar power tower and parabolic dish system are viable options for installation.
- However, economically, the SPT shows more attractive results than the PDS in every economic criterion selected in the current study. Thus, the conclusion can be drawn that, in Jodhpur, India, the solar power tower (SPT) is more viable than the solar parabolic dish system (PDS), both technically and economically.

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