Impact of Incentives Towards Lowering the Levelized Cost of Electricity of Concentrating Solar Power Plants in India

Tarun Kumar Aseri[1,2], Chandan Sharma[2], Tara C. Kandpal[1]

[1] Department of Energy Science and Engineering, Indian Institute of Technology Delhi (India)

[2] Mechanical Engineering Department, Engineering College, Ajmer (India)

Abstract

The present study aims to assess the impact of various feasible incentives toward lowering the levelized cost of electricity (LCOE) of concentrating solar power (CSP) plants in India. For this purpose, two aspects (a) effect of increasing the extent of incentives on LCOE and (b) effect of different incentives for a given fixed government budgetary allocation for incentivization have been considered. 100 MW nominal capacity CSP plants with (i) wet-cooled parabolic trough solar collector and (ii) dry-cooled central tower receiver based CSP plants with the provision of 6.0 h and 12.0 h of thermal energy storage (TES) have been considered. From the results, it is observed that the provision of incentives in the early stage of useful life of the CSP plant leads to relatively higher reduction in LCOE. As the CSP plants with the provision of TES can deliver electricity during peak demand periods, the break-even value of time-of-delivery tariff for the electricity delivered by the CSP plants has also been estimated.

Keywords: CSP plant, financial incentives, levelized cost of electricity, thermal energy storage

1. Introduction

Among the two options for harnessing solar energy to produce electricity, the solar thermal route can facilitate relatively inexpensive thermal energy storage (TES) as compared to the storage options with photovoltaic (PV) route and helps in improving the dispatch ability of the electricity delivery due to variable and intermittent solar resource (REN21, 2021). However, presently the levelized cost of electricity (LCOE) for concentrating solar power (CSP) plants is much higher than that for PV power plants. Thus, several potential strategies are being explored to make them financially competitive as against other renewable and fossil fuel based electricity generation options (IRENA, 2022). The prominent strategies include (a) adoption of emerging CSP technologies (Aseri et al., 2020), (b) indigenization of components of CSP plants (ESMAP, 2013), (c) installation of large size plants to take benefit of economy of scale (Aseri et al., 2022), (d) improved financing structure (Mendelsohn et al., 2012) and (e) provision of incentive(s) (Kulichenko and Wirth, 2011). Amongst these measures, the appropriately designed financial/fiscal and regulatory incentives to stimulate the deployment of renewable energy based electricity generation (including CSP plants) is required. Several policy measures have been taken and/or incentives have been provided in the early stage of deployment of renewable energy based power generation options by many countries in the world (Atalay et al., 2017; DESIRE, 2020; Kulichenko and Wirth, 2011; MASEN, 2021). The primary aim of these policy measures is to provide either direct cash grant or tax rebate to project developer(s)/investor(s) for a specified period to make cash flow profitable and make the projects financially viable (Aseri et al., 2020b; Parrado et al., 2016; San Miguel and Corona, 2018).

In the first phase (1984-1990) of deployment of CSP plants in the Californian desert (USA), accelerated depreciation along with exemption from property tax was provided (SolarPACES, 2021). In the second phase (2007-2013), the deployment of CSP plants in Spain was stimulated with the provision of feed-in-tariff (FiT) with successful deployment of 49 CSP plants with total nominal capacity of 2.3 GW (Martín et al., 2015; Lilliestam et al., 2017). In the third phase, after the year 2013, incentives such as production and investment tax credits for equity investors and benefits of selling certified emission reduction units and/or renewable energy certificates have been provided (Abolhosseini and Heshmati, 2014; Madaeni et al., 2012; Malagueta et al., 2013; Sioshansi and Denholm, 2010) to promote the diffusion of CSP plants.

From the literature review, it was observed that specific studies pertaining to impact assessment of incentives for large scale dissemination of CSP plants has not been reported in Indian context. In order to design and implement appropriate incentivizing strategies for CSP based electricity generation in India, it would be highly insightful and useful to assess the impact of different potential incentives on the LCOE. In view of this, as a preliminary attempt (i) the effect of an increase in the extent of incentive on the LCOE has been studied and (ii) for a given fixed budget allocated by the government for incentivization, the maximum possible extent of each incentive and consequently its

doi:10.18086/eurosun.2022.18.01 Available at http://proceedings.ises.org

impact on the LCOE have been estimated. Since, unlike the case of PV and wind power plants, the CSP plants with TES can deliver electricity during peak demand periods, the break-even value of time-of-delivery tariffs for the electricity delivered have also been estimated.

2. Methodology

The location of Mandla, in the state of Madhya Pradesh was selected out of the potential locations identified in India for the deployment of CSP plants by Sharma et al. (2015) based on an annual threshold value of direct normal irradiance. 100 MW nominal capacity wet-cooled parabolic trough solar collector (PTSC) based and dry-cooled central tower receiver (CTR) based CSP plants with the provision of 6.0 and 12.0 hours of TES are considered for the analysis (Aseri et al., 2020a). A schematic of the methodology adopted in the study is presented in Fig. 1. The detailed procedure of the same is presented in the following paragraphs.

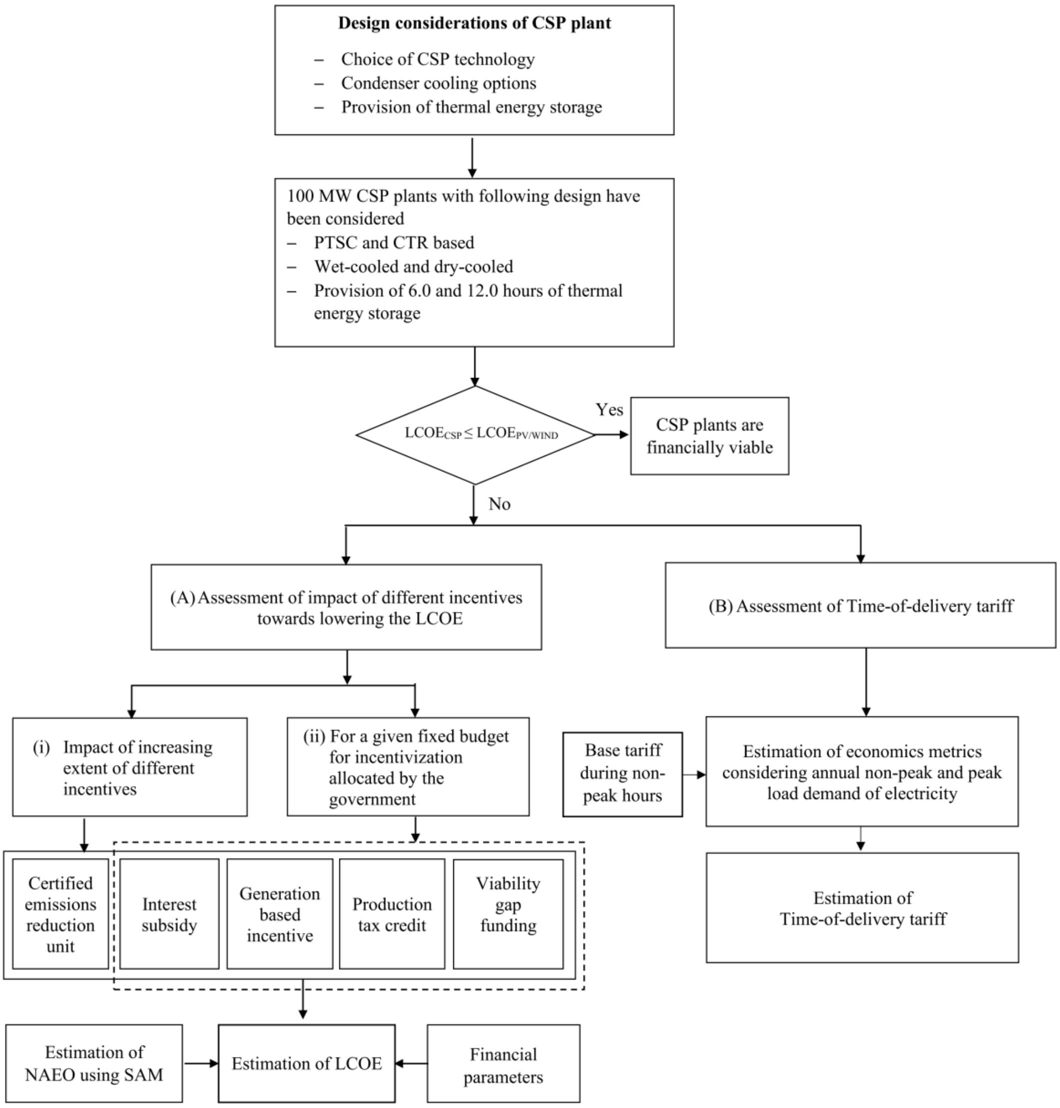

Fig. 1 Methodology for assessing impact of different incentives on LCOE and estimation of time-of-delivery tariff

Estimation of LCOE

The following expression is used to estimate the value of LCOE and the same allows to consider the time variation in the annual cost to be incurred in the project as well in the net annual electricity output delivered by the project.

$$LCOE\ (US\ \$/MWh) = \left(\frac{d(1+d)^n}{(1+d)^n - 1}\right) \times \sum_{i=1}^{n} \frac{AC_i \times (1+d)^{-i}}{NAEO_i \times 10^3} \quad \text{(Eq. 1)}$$

The annual cost (AC_i) of i^{th} year comprises of annual cost of operation and maintenance of the plant, amount of interest on working capital, annual amount of return on equity and amount of annual loan repayment including the principal component and the interest on the loan. Moreover, monetary incentives available to the project have also been internalized as negative costs while estimating the annual cost. The effective annual cost (AC) for the plant is estimated as :

$$Effective\ annual\ cost = \begin{bmatrix} Cost\ of\ O\&M \\ including \\ escalation \end{bmatrix} + \begin{bmatrix} Interest\ on \\ working \\ capital \end{bmatrix} + \begin{bmatrix} Return\ on \\ equity \\ to\ investor \end{bmatrix} + \begin{bmatrix} Loan\ repayment \\ including \\ principal \\ and\ interest \end{bmatrix} - \begin{bmatrix} Applicable\ monetory\ benefits \\ due\ to\ incentive(s) \end{bmatrix} \quad \text{(Eq. 1)}$$

In the present study, the discount rate (d) has been estimated as the weighted average cost of capital (WACC) for the project using the following expression:

$$d = \text{WACC} = I_d F_d + R_e F_e \quad \text{(Eq.3)}$$

The net annual electricity output (NAEO) and other performance metrics for the CSP plants considered in the study, have been estimated using System Advisor Model (SAM, 2021). The hourly values of weather data for Mandla have been obtained from the National Solar Radiation Data Base, NREL, USA (NSRDB, 2018).

With the use of inventory of materials based approach proposed by authors (Aseri et al., 2020b), the capital costs of PTSC and CTR based CSP plants have been estimated. To decide the applicable values of financial parameters for the CSP plants, corresponding values as suggested by the CERC (Central Electricity Regulatory Commission, Government of India), have been considered (CERC, 2020) and the same are presented in Tab. 1. A spread sheet (Microsoft Excel) model has been developed to estimate the annualized cost, extent of incentive and subsequently their effect in reducing the LCOE. Assumptions made for assessing the efficacy of the incentives considered in the study are presented in Tab. 2.

Tab. 1. Values of financial parameters considered in the present analysis (CERC, 2020)

Financial parameter	Unit	Value
Share of debt: equity	fraction	0.7:0.3
Debt repayment (loan) term	Years	15
Annual rate of Interest rate on debt	fraction	0.0967
Annual rate of return on equity	fraction	0.14
Discount rate	fraction	0.1097
Annual rate of income tax	fraction	0.35
Amount of working capital	-	One-month O&M, 15% of O&M for spares, 2 months receivables
Annual rate of interest on working capital	fraction	0.1117
Annual rate of depreciation for loan term	fraction	0.0467
Annual rate of depreciation after loan term	fraction	0.02
Annual cost of operation and maintenance	US$/MW	31550
Annual rate of escalation in operation and maintenance cost	fraction	0.0572
Salvage value (as a fraction of the capital cost) at the end of useful life	fraction	0.10
Useful life of the plant	Years	30

Extent of incentives

While assessing the effect of increasing the extent of incentives on LCOE, the values for each incentive is selected based on literature and the same are presented in Tab. 3 (Aryani et al., 2020; Comello and Reichelstein, 2016; Ozcan, 2014; Thapar et al., 2016).

In order to assess the efficacy of incentives in lowering the LCOE, it is assumed that the government of India is willing to contribute financial support equivalent to a certain fraction of the capital cost for providing any of the four incentives indicated in Fig. 1. As an example, noting the fact that 30% investment tax credit was provided in the USA for rooftop PV plants (Comello and Reichelstein, 2016; DOE, 2021), the same value has been considered in

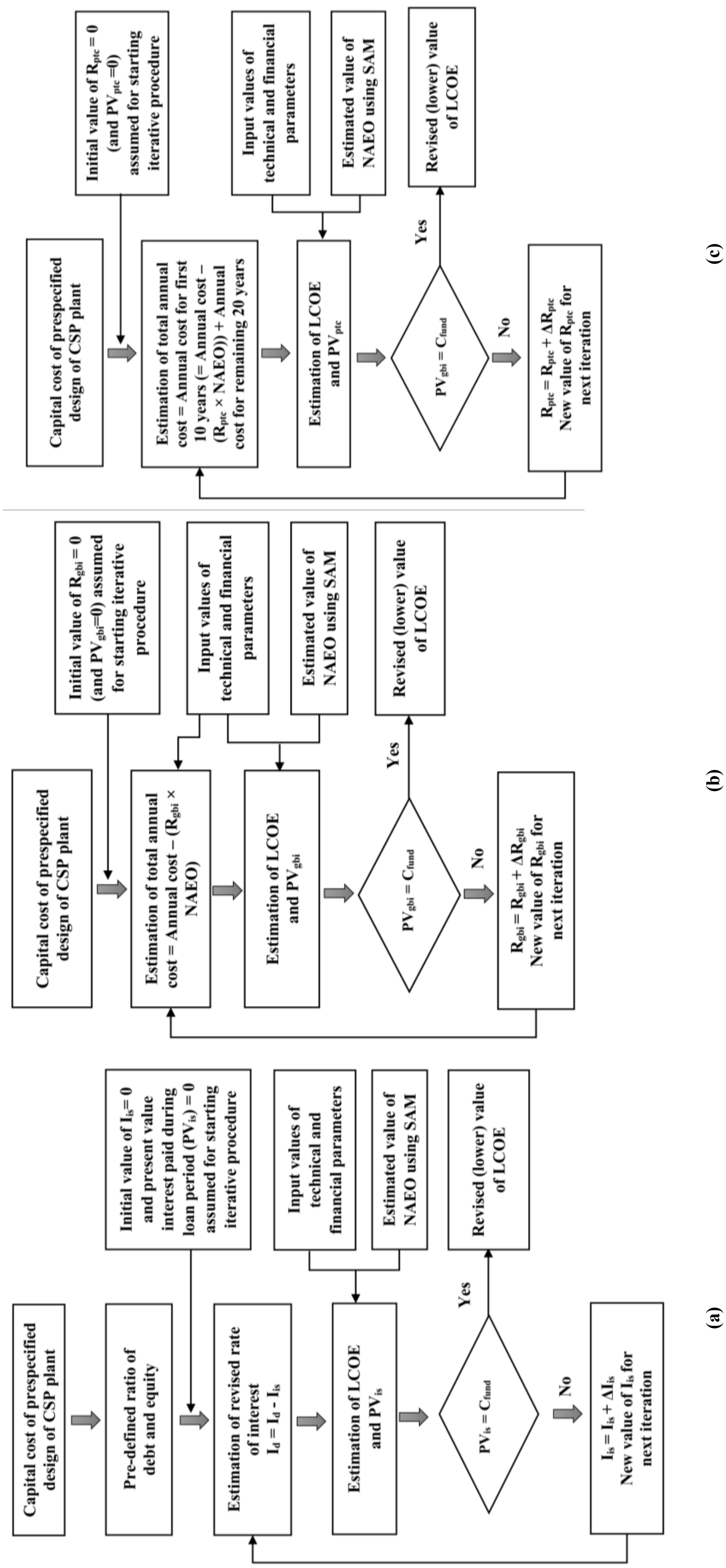

Fig. 2 Iterative procedure used to estimate the extent of (a) interest subsidy, (b) generation based incentive and (c) production tax credit

the present study to decide the amount of government funds that can be used for the incentivization of CSP plants in India through any of the incentives considered in the study. It is worth mentioning that to estimate the value of reduced LCOE due to the provision of the incentive considered, an iterative procedure has been used for the cases of interest subsidy, generation based incentive and production tax credit and the same is presented in Fig. 2.

Tab. 2. Assumptions made for studying the impact of incentives on the LCOE

Incentive	Assumption
Viability gap funding	Affects both the debt and equity components in 0.7:0.3 ratio
Interest subsidy	Affects only the loan repayment component
Generation based incentive	Provided for the entire useful life of the CSP plant
Production tax credit	Benefits of PTC shall be applicable for the first ten years of the useful life of the CSP plant
Certified emission reduction unit	– Benefits of CERU shall be applicable for the entire useful life of the CSP plant – The mean of the weighted average rate of CO_2-eq emissions of the past three years (2018-19, 2019-20 and 2020-21) in India for arriving at a value of 0.81 tCO_2/MWh for use in the study (CEA, 2022)

Tab. 3 Range of values of individual incentives considered in the study for assessing their effect on LCOE (Aryani et al., 2020; Comello and Reichelstein, 2016; Ozcan, 2014; Thapar et al., 2016)

Incentive	Unit	Value(s) considered in the analysis
Viability gap funding	% of capital cost	5, 10, 15, 20, 30, 35
Interest subsidy	%	1, 2, 3, 4, 5, 6, 7, 8
Generation based incentive	US$/MWh	5, 10, 15, 20, 25, 30, 40, 45
Production tax credit	US$/MWh	5, 10, 15, 20, 25, 30, 40, 45
Certified emission reduction unit	US$/$tCO_2$	10, 20, 30, 40, 50, 60, 70, 80, 90

Provision of time-of-delivery (ToD) tariff for CSP plants

The provision of TES in CSP plants can improve their dispatch ability and thus the plants can deliver electricity during the period of higher/peak demand besides enabling them to supply electricity during off-sunshine hours. Moreover, CSP plants with TES can supply electricity without introducing any grid stability issues. However, since the CSP plants with TES are relatively costlier than the plant without TES, a provision of time-of-delivery tariff for the electricity delivered by CSP plants at the time of higher demand of electricity may help to improve their financial attractiveness. In India, several electricity distribution utilities have adopted the ToD tariff in the form of surcharge/rebate on the base tariff for commercial users demanding load of more than 20kW and a summary of annual variation of tariff in states of India is presented in Fig. 3. The distribution utilities are applying surcharges during morning and evening peak demand periods and offering rebate during off-peak hours on the base tariff. In view of this, in the present study, it is assumed that during off-peak hours, the applicable tariff for electricity delivered by the CSP plants will be equal to average power purchase cost (APPC) of state electricity distribution utilities of Madhya Pradesh. The mean of APPC for last three financial years 2019-20 to 2020-22 has been estimated at US $50.9 per MWh (MPERC, 2022, 2021, 2020) and the same has been considered as a base tariff during off-peak hours (Tab. A.1 of Appendix A). The values of tariffs during the peak demand period, which would ensure the break-even condition for the CSP plants also have been estimated.

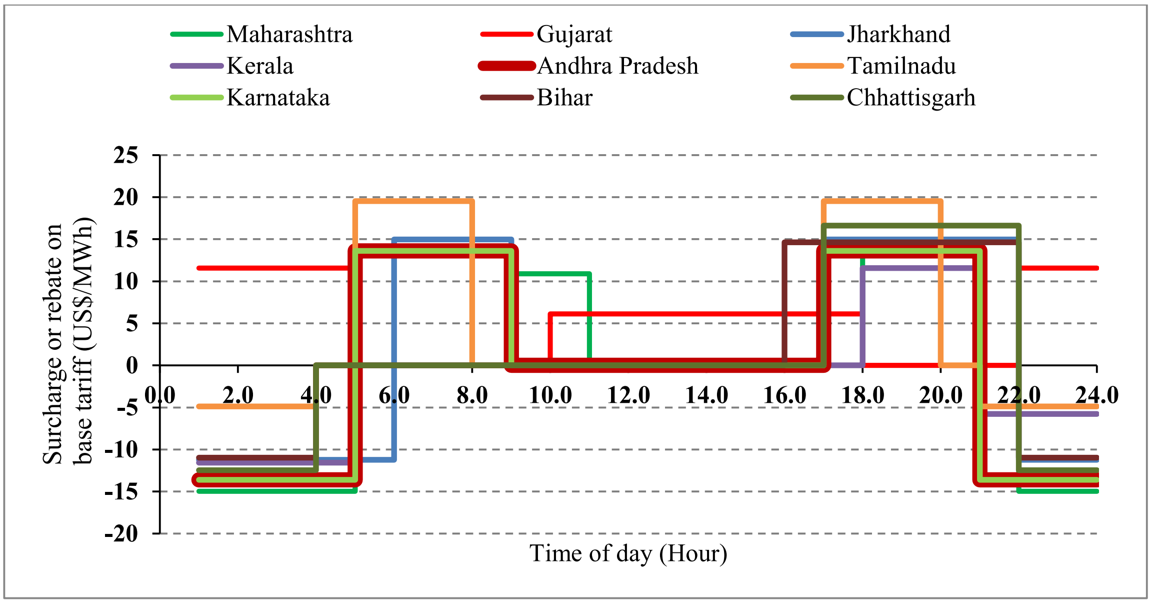

Fig. 3 Variation of surcharge/rebate in the electricity tariff imposed by different states regularities in India

3. Results and discussion

Using inventory of materials based approach, the capital costs of wet-cooled PTSC based CSP plants with 6.0 h and 12.0 h of TES are estimated at US $366.08 million and US $519.75 million respectively. The corresponding values for dry-cooled CTR based plants are estimated at US $346.96 million and US $486.03 million. As expected, with an increase in capacity of TES, the capital cost increases but due to higher incremental benefits than the incremental cost, the LCOE decreases that shows the presence of economy of scale with respect to the thermal energy storage capacity of the CSP plant. The effect of economy of scale is observed to be higher for CTR based plants as compared to PTSC based plants. Considering financial parameters (Tab. 1), the estimate of base LCOE for CTR based plant with 12.0 h of TES (US$100.5/MWh) is lower by 3.9% than that of plant with 6.0 h of TES (US $104.6/MWh). However, in PTSC based plants, the effect of economy of scale is observed to be only marginal as the values of base LCOE are very close and estimated at US$112.8/MWh and US$112.3/MWh for 6.0 h and 12.0 h of TES, respectively.

With the assumed range of different incentives, the values of LCOE and the cumulative present value of incentives provided each year have been estimated and are summarized in

for dry-cooled CTR based CSP plant with 6.0 hours of TES. Similar exercises have also been carried out for other CSP plants considered in the study. From the results obtained, it is observed that, as expected, with an increase in the extent of incentive, the LCOE decreases and the cumulative present value of amount required for incentivization increases. While comparing the amount of incentive required for the plants based on two different CSP technologies and two TES capacities, it may be observed that CTR based plants with 6.0 hours of TES requires least financial support.

As mentioned earlier, an attempt to assess the efficacy of individual incentives for a given fixed budget for incentivization allocated by the government has also been made and it is proposed that the Indian government shall contribute (C_{fund}) 30% of the capital cost of CSP plant. For this purpose, the capital costs of CTR based CSP plants have been considered as the same is lower than the capital cost of PTSC based CSP plants and the same are estimated US $104.1 million and US $145.8 million for CSP plants with 6.0 h and 12.0 h of TES, respectively. Using these values and following the iterative procedure, the maximum extent of each incentive and reduction in LCOE are estimated and the results are presented in Tab. 5. Fig. 4 represents the achieved percentage reduction in LCOE with the provision of incentives. From the results obtained, it can be observed that for a given fixed budget allocated by the government for incentivization in terms of viability gap funding, the LCOE can be reduced in the range of 26.4-28.2% from the base value of LCOE. The other incentives considered in the study such as interest subsidy (soft loan), generation based incentive and production tax credit are equally effective and can reduce the LCOE in the range of 25.8-27.5% from the based value of LCOE. Results also reveal that for a given fixed budget by the government, the LCOE of CTR based plants reduces by a somewhat greater extent as compared to the reduction likely to be achieved in the LCOE of PTSC based plants.

Tab. 4 Estimates of LCOE and cumulative present value of provision of incentives provided for dry-cooled CTR based CSP plant with 6.0 hours of TES

VGF (Fraction)	LCOE (US$/MWh)	Cumulative present value of provision of VGF (Million US$)	Interest subsidy (Fraction)	LCOE (US$/MWh)	Cumulative present value of provision of interest saved (Million US$)	Generation based incentive (US$/MWh)	LCOE (US$/MWh)	Cumulative present value of provision of GBI (Million US$)	Production tax credit (US$/MWh)	LCOE (US$/MWh)	Cumulative present value of provision of PTC (Million US$)	Certified emission reduction unit (US$/t$CO_2$)	LCOE (US$/MWh)	Cumulative present value of provision of CERU (Million US$)
0.00	104.6	0.0	0.00	104.6	0.0	0.0	104.6	0.0	0	104.6	0.0	0	104.6	0.0
0.05	99.8	17.3	0.01	101.5	11.5	5.0	99.6	18.4	5	101.3	12.4	10	96.5	29.8
0.10	95.0	34.7	0.02	98.4	23.0	10.0	94.6	36.8	10	97.9	24.9	20	88.4	59.6
0.15	90.1	52.0	0.03	95.3	34.5	15.0	89.6	55.2	15	94.5	37.3	30	80.3	89.4
0.20	85.3	69.4	0.04	92.1	46.0	20.0	84.6	73.6	20	91.1	49.8	40	72.2	119.2
0.25	80.6	86.7	0.05	89.0	57.6	25.0	79.6	92.0	25	87.7	62.2	50	64.1	149.0
0.30	75.7	104.1	0.06	85.9	69.1	30.0	74.6	110.4	30	84.3	74.7	60	56.0	178.8
0.35	70.9	121.4	0.07	82.7	80.6	35.0	69.6	128.8	35	81.0	87.1	70	47.9	208.6
			0.08	79.6	92.1	40.0	64.6	147.2	40	77.6	99.6	80	39.8	237.4
						45.0	59.6	165.6	45	74.2	112.0	90	31.7	268.2

Tab. 5 Effect of different incentives on LCOE (for the same budgetary allocation by the government for incentivization)

Modality		Unit	6.0 h TES		12.0 h TES	
			PTSC wet	CTR dry	PTSC wet	CTR dry
Capital cost of CSP plant		Million US$	366.08	346.96	519.75	486.03
NAEO		GWh	411.3	422.2	576.5	605.4
Capacity utilization factor		fraction	0.470	0.482	0.658	0.691
Annual water requirement		m^3	1301745	105690	1792380	151073
Base LCOE		US$/MWh	112.8	104.6	112.3	100.5
Proposed contribution from government		Million US$	104.1		145.8	
Viability gap funding	Feasible extent of VGF	%	28.4	30.0	28.1	30.0
	LCOE with VGF	US$/MWh	83.1	75.7	82.6	72.2
Interest subsidy	Allowable extent of interest subsidy	%	8.57	9.05	8.46	9.04
	Reduced interest rate	%	1.10	0.62	1.21	0.63
	LCOE with interest subsidy	US$/MWh	83.8	76.4	83.3	72.9
Generation based incentive	Allowable extent of GBI	US$/MWh	29.0	28.3	29.0	27.6
	LCOE with GBI	US$/MWh	83.8	76.3	83.3	72.9
Production tax credit	Extent of PTC	US$/MWh	42.9	41.8	42.9	40.8
	LCOE with PTC	US$/MWh	83.8	76.3	83.3	72.9

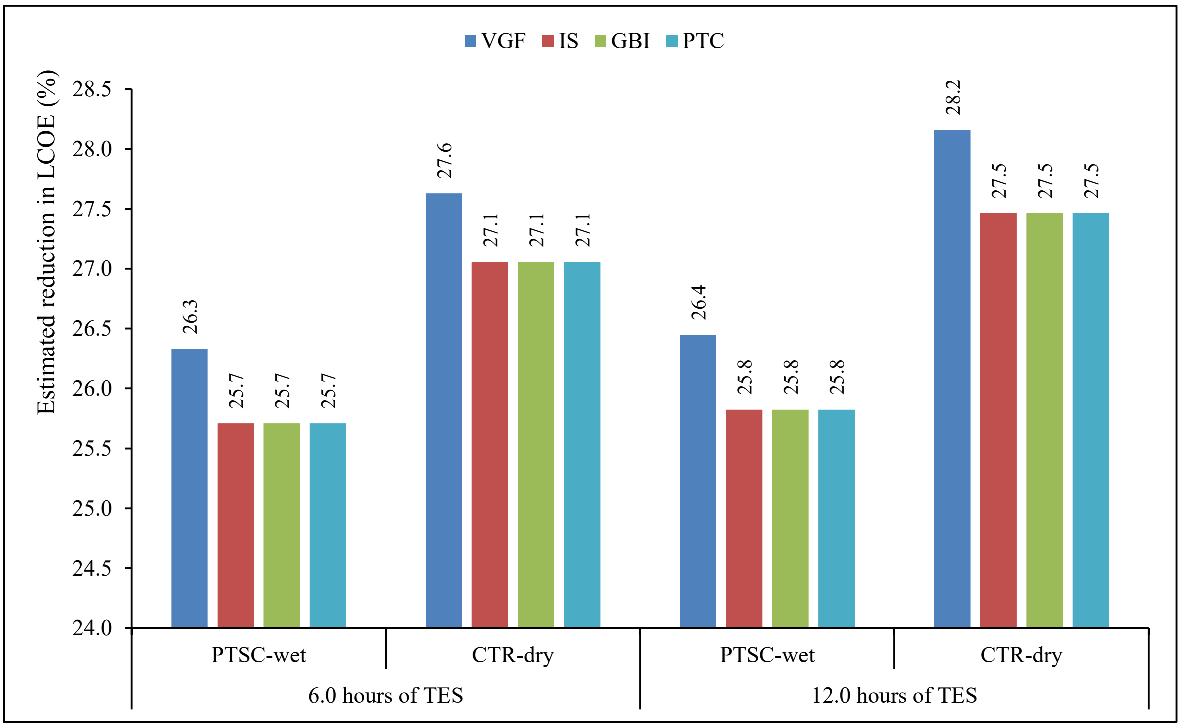

Fig. 4 Estimated reduction in LCOE for a given fixed budget for incentivization allocated by the government to CSP plants

As mentioned earlier, a preliminary attempt has also been made to estimate the break-even values of ToD tariffs for the electricity delivered by CSP plants with the provision of TES considering the base tariff at US $50.9/MWh during off-peak hours and the results of the same are presented in Tab. 6. The estimated values of ToD tariffs that would ensure a break-even condition for PTSC-wet and CTR-dry plants with 6.0 hours of TES are US $174.7/MWh and US $158.3/MWh respectively. For CSP plants with 12.0 hours of TES, the corresponding values of required ToD tariffs are estimated at US $143.0/MWh and US $125.3/MWh.

Tab. 6. Estimates of break-even values of electricity for PTSC and CTR based CSP plants during the peak demand

CSP plant	Hours of TES	Duration of non-peak demand of electricity in a day (Hours)	Duration of peak demand of electricity in a day (Hours)	Total duration of electricity delivered by the plant in a day (Hours)	Capital cost (Million US$)	NAEO (GWh)	LCOE (US$/ MWh)	ToD tariff (US $/MWh)
PTSC-wet	6.0	6.0	6.0	12.0	366.08	411.3	112.8	174.7
	12.0	6.0	12.0	18.0	219.75	576.5	112.3	143.0
CTR-dry	6.0	6.0	6.0	12.0	346.96	422.2	104.6	158.3
	12.0	6.0	12.0	18.0	486.03	605.4	100.5	125.3

4. Concluding remarks

The present study aims to identification of effectiveness of incentives for CSP plants in India to make them financially competitive. For this purpose, 100 MW CSP plants based on two CSP technologies (i.e., PTSC and CTR), two condenser cooling options (i.e., wet cooling in PTSC and dry cooling in CTR based plants) and two capacities of thermal energy storage (i.e., 6 hours and 12 hours) have been considered. The techno-economic performance has been undertaken for CSP plants at Mandla (Madhya Pradesh) using SAM and financial parameters expected to be applicable in Indian perspective.

As expected from the results obtained, it is observed that with an increase in the extent of an incentive, the LCOE decreases. The viability gap funding can reduce the LCOE by higher amount at lower cost to the government. Amongst the four plants, dry-cooled CTR based CSP plant with 6.0 hours of TES required the least amount of incentive.

While assessing the efficacy of incentives for a given fixed budget allocated by the government, it is noted that by providing viability gap funding the LCOE can be reduced in the range of 26.4-28.2% from the base value of LCOE. The other incentives considered in the study such as interest subsidy (soft loan), generation based incentive, and production tax credit are equally effective and can reduce the LCOE in the range of 25.8-27.5% from the based value of LCOE.

Considering base tariff (US$ 50.9/MWh) during non-peak demand of electricity, the time-of-delivery tariffs for CSP plants with 6.0 hours of TES are estimated at US $174.7/MWh and US $158.3/MWh for PTSC and CTR based plants respectively. The corresponding values for CSP plants with 12.0 hours of TES have been estimated at US $143.0/MWh and US $125.3/MWh.

Acknowledgments

The authors are thankful to the administration of Engineering College Ajmer, Rajasthan (India) and acknowledge the Department of Technical Education, Government of State of Rajasthan for providing permission to the first author (Tarun Kumar Aseri) to pursue doctoral research work at the Department of Energy Science and Engineering, Indian Institute of Technology Delhi.

References

Abolhosseini, S., Heshmati, A., 2014. The main support mechanisms to finance renewable energy development. Renew. Sustain. Energy Rev. 40, 876–885. https://doi.org/10.1016/j.rser.2014.08.013

Aryani, M., Ahmadian, M., Sheikh-El-Eslami, M.K., 2020. Designing a regulatory tool for coordinated investment in renewable and conventional generation capacities considering market equilibria. Appl. Energy 279, 115728. https://doi.org/10.1016/j.apenergy.2020.115728

Aseri, T.K., Sharma, C., Kandpal, T.C., 2022. A techno-economic appraisal of parabolic trough collector and central tower receiver based solar thermal power plants in India: Effect of nominal capacity and hours of thermal energy storage. J. Energy Storage 48, 103976. https://doi.org/10.1016/j.est.2022.103976

Aseri, T K, Sharma, C., Kandpal, T.C., 2020. Cost reduction potential in parabolic trough collector based CSP plants: A case study for India. Renew. Sustain. Energy Rev. 138, 110658. https://doi.org/10.1016/j.rser.2020.110658

Aseri, T.K., Sharma, C., Kandpal, T.C., 2020a. Estimating capital cost of parabolic trough collector based concentrating solar power plants for financial appraisal: Approaches and a case study for India. Renew. Energy 156, 1117–1131. https://doi.org/10.1016/j.renene.2020.04.138

Aseri, T.K., Sharma, C., Kandpal, T.C., 2020b. Assessment of water availability for wet cooling at potential locations for solar thermal power generation in India. Int. J. Ambient Energy 41, 1126–1141. https://doi.org/10.1080/01430750.2018.1507926

Atalay, Y., Kalfagianni, A., Pattberg, P., 2017. Renewable energy support mechanisms in the Gulf Cooperation Council states: Analyzing the feasibility of feed-in tariffs and auction mechanisms. Renew. Sustain. Energy Rev. 72, 723–733. https://doi.org/10.1016/j.rser.2017.01.103

CEA, 2022. CDM – CO2 Baseline Database Version 15.0, 16.0 and 17.0, Central Electricity Authority New Delhi. https://cea.nic.in/cdm-co2-baseline-database/?lang=en (accessed 9.1.22).

CERC, 2020. Determination of levellised generic tariff for FY 2020-21 under Regulation 8 of the Central Electricity Regulatory Commission (Terms and Conditions for Tariff determination from Renewable Energy Sources) Regulations, 2020,. Cent. Electr. Regul. Comm. http://www.cercind.gov.in/2020/orders/13-SM-2020.pdf (accessed 4.3.21).

Comello, S., Reichelstein, S., 2016. The U.S. investment tax credit for solar energy: Alternatives to the anticipated 2017 step-down. Renew. Sustain. Energy Rev. 55, 591–602. https://doi.org/10.1016/j.rser.2015.10.108

DESIRE, 2020. Database of State Incentives for Renewables and Efficiency, funded by U.S. Department of Energy and maintained by North Carolina State University. N.C. Clean Energy Technol. Cent. https://www.dsireusa.org/ (accessed 6.27.21).

DOE, 2021. Residential and Commercial ITC Factsheets. U.S. Dep. Energy. https://www.energy.gov/eere/solar/articles/residential-and-commercial-itc-factsheets (accessed 12.6.21).

ESMAP, 2013. Development of Local Supply Chain: The Missing Link for Concentrated Solar Power Projects in India, Energy Sector Management Assistance Program. Washington, USA.

FBIL, 2022. Foreign Exchange, Administering Independent Benchmarks. Financ. Benchmarks India Pvt. Ltd. https://www.fbil.org.in/ (accessed 9.2.22).

IRENA, 2022. Renewable power generation costs in 2021, International Renewable Energy Agency. Abu Dhabi.

Kulichenko, N., Wirth, J., 2011. Regulatory and Financial Incentives for Scaling Up Concentrating Solar Power in Developing Countries, The World Bank Group, Washington, DC. Discussion Paper No.24, June 2011.

Lilliestam, J., Labordena, M., Patt, A., Pfenninger, S., 2017. Empirically observed learning rates for concentrating solar power and their responses to regime change. Nat. Energy 2, 1–6. https://doi.org/10.1038/nenergy.2017.94

Madaeni, S.H., Sioshansi, R., Denholm, P., 2012. Estimating the capacity value of concentrating solar power plants: A case study of the southwestern United States. IEEE Trans. Power Syst. 27, 1205–1215. https://doi.org/10.1109/TPWRS.2011.2179071

Malagueta, D., Szklo, A., Borba, B.S.M.C., Soria, R., Aragão, R., Schaeffer, R., Dutra, R., 2013. Assessing incentive policies for integrating centralized solar power generation in the Brazilian electric power system. Energy Policy 59, 198–212. https://doi.org/10.1016/j.enpol.2013.03.029

Martín, H., De La Hoz, J., Velasco, G., Castilla, M., García De Vicuña, J.L., 2015. Promotion of concentrating solar thermal power (CSP) in Spain: Performance analysis of the period 1998-2013. Renew. Sustain. Energy Rev. 50, 1052–1068. https://doi.org/10.1016/j.rser.2015.05.062

MASEN, 2021. Morocco Solar Plan. Moroccan Agency for Solar Energyx. https://www.masen.ma/ (accessed 6.28.21).

Mendelsohn, M., Kreycik, C., Bird, L., Schwabe, P., Cory, K., 2012. The Impact of Financial Structure on the Cost of Solar Energy The Impact of Financial Structure on the Cost of Solar Energy. Technical Report: NREL/TP-6A20-53086. Natl. Renew. Energy Lab. USA 1–40.

MPERC, 2022. Aggregate Revenue Requirement and Retail Supply Tariff Order For FY 2021-22, Retail Supply Tariff Order FY 2021-22.

MPERC, 2021. Aggregate Revenue Requirement and Retail Supply Tariff Order For FY 2020-21, Retail Supply Tariff Order FY 2020-21.

MPERC, 2020. Aggregate Revenue Requirement and Retail Supply Tariff Order For FY 2019-20, Retail Supply Tariff Order FY 2019-20.

NSRDB, 2018. The National Solar Radiation Database (NSRDB). Natl. Renew. Energy Lab. USA.

https:/nsrdb.nrel.gov/ (accessed 4.3.18).

Ozcan, M., 2014. Assessment of renewable energy incentive system from investors' perspective. Renew. Energy 71, 425–432. https://doi.org/10.1016/j.renene.2014.05.053

Parrado, C., Marzo, A., Fuentealba, E., Fernández, A.G., 2016. 2050 LCOE improvement using new molten salts for thermal energy storage in CSP plants. Renew. Sustain. Energy Rev. 57, 505–514. https://doi.org/10.1016/j.rser.2015.12.148

SAM, 2021. System Advisor Model, Version 2021.12.02 Revision 1, SSC 238. National Renewable Energy Laboratory, Alliance for Sustainable Energy, LLC for Department of Energy, USA. https://sam.nrel.gov/ (accessed 3.3.22).

San Miguel, G., Corona, B., 2018. Economic viability of concentrated solar power under different regulatory frameworks in Spain. Renew. Sustain. Energy Rev. 91, 205–218. https://doi.org/10.1016/j.rser.2018.03.017

Sharma, C., Sharma, A.K., Mullick, S.C., Kandpal, T.C., 2015. Assessment of solar thermal power generation potential in India. Renew. Sustain. Energy Rev. 42, 902–912. https://doi.org/10.1016/j.rser.2014.10.059

Sioshansi, R., Denholm, P., 2010. The value of concentrating solar power and thermal energy storage. IEEE Trans. Sustain. Energy 1, 173–183. https://doi.org/10.1109/TSTE.2010.2052078

SolarPACES, 2021. Concentrating Solar Power Projects. Natl. Renew. Energy Lab. USA. https://solarpaces.nrel.gov/ (accessed 3.12.22).

Thapar, S., Sharma, S., Verma, A., 2016. Economic and environmental effectiveness of renewable energy policy instruments: Best practices from India. Renew. Sustain. Energy Rev. 66, 487–498. https://doi.org/10.1016/j.rser.2016.08.025

Appendix A

Nomenclature

Symbols

AC	Annual cost (Million US$)	NAEO	Net annual electricity output (GWh)
C_{fund}	Public/government fund (Million US$)	PV_{gbi}	Cumulative present value of annual cost of GBI (Million US$)
d	Discount rate (Fraction)		
F_d	Share of debt (Fraction)	PV_{is}	Cumulative present value of annual cost of interest paid on loan (Million US$)
F_e	Share of equity (Fraction)		
I_d	Interest rate on debt (Fraction)	PV_{ptc}	Cumulative present value of annual cost of PTC (Million US$)
I_{is}	Interest rate on loan (Fraction)		
n	Useful life of CSP plant (Years)	R_e	Rate of return on equity (Fraction)

Abbreviations

CERU	Certified emission reduction unit	PTSC	Parabolic trough solar collector
CSP	Concentrating solar power	PV	Photovoltaic
CTR	Central tower receiver	REC	Renewable energy certificate
FiT	Feed-in-Tariff	RPO	Renewable purchase obligation
GBI	Generation based incentives	SAM	System Advisor Model
IS	Interest subsidy	TES	Thermal energy storage
LCOE	Levelized cost of electricity	ToD	Time-of-delivery
O&M	Operation and maintenance	VGF	Viability gap funding
PTC	Production tax credit	WACC	Weighted average capital cost

Tab. A.1 Estimates of average unit cost of electricity for the state of Madhya Pradesh for the financial years 2019-20 to 2021-22 (MPERC, 2022, 2021, 2020)

Financial Year	Average power purchase cost (INR/kWh)	Conversion rate 1 US$ to INR#	Average power purchase cost (US$/kWh)
2019-20	3.99	70.88	56.3
2020-21	3.43	74.20	46.2
2021-22	3.74	74.51	50.2
	Mean of average power purchase cost (US$#/MWh) →		**50.9**

(FBIL, 2022)