IJESG
e-ISSN 2636-7904
International Journal of Energy and Smart Grid
Vol 8, Number 1, 2023
Doi: 10.55088/ijesg.1234523

Research Article

TECHNO-ECONOMIC FEASIBILITY ANALYSIS OF A LARGE-SCALE PARABOLIC TROUGH THERMAL POWER PLANT IN EFFURUN-WARRI, NIGERIA

John Akpaduado**, *Joseph Oyekale

Department of Mechanical Engineering, Federal University of Petroleum Resources Effurun, PMB 1221 Effurun, Nigeria.
*Corresponding Author: johnakpoduado909@gmail.com

Abstract *In the modern world, solar energy is one of the most mature renewable energy resources for electricity generation. Because of the growing interest in green energy and CO_2 reduction, concentrated power technologies have gained prominence all over the world. Several parabolic trough power plants are currently operational in various parts of the world. However, despite the region's favorable weather conditions, Nigeria and Sub-Saharan Africa have yet to adopt this technology. To galvanize the integration of solar energy into the energy infrastructure in Nigeria, technical and economic feasibility studies are required. This paper presents a techno-economic viability assessment of a 25 MW Parabolic Trough solar thermal power plant for electricity generation in Effurun-Warri, Nigeria. The System Advisor Model (SAM) software was used for the analysis, based on the validated technical and financial models inbuilt into the software. Results showed that the plant is technically feasible in Effurun-Warri with a capacity factor of over 35%, which compares favorably with other similar plants across the globe. However, the levelized cost of electricity (LCOE) of 11.87 ₵/kWh obtained is significantly higher than the subsidized cost of electricity in the country, by 99%, leading to a negative net present value of the project. To improve cost, optimized design parameters of the plant should be adopted for performance simulation in the SAM software.*

Keywords - *Solar Energy; System Advisor Model (SAM); Concentrated Solar Power (CSP); Parabolic Trough Collectors (PTC); Techno-economic Assessment.*

Received: 15 January 2023 *Accepted: 26 November 2023*

1. Introduction

There has been an explosion in population in recent times, particularly in developing regions such as Africa [1]. Several consequences of this population explosion now live with humans globally today; including energy poverty, food insecurity, spontaneous increase in greenhouse gases emissions, global warming, etc. Reducing the impacts of these adverse effects on the human race is a global concern today, and several scientists have been working hard in this regard. Specifically, a lot of efforts are ongoing to improvise energy and transportation systems that would emit little or no hazardous gases into the environment, fuelled principally by renewable energy resources [2]. However, although such solar, wind, biomass, and other renewable energy and transportation systems are rapidly gaining traction in the developed world in terms of development and commercialization, little is yet to be desired of these systems in many developing countries. Among the causes of low application of renewable energy systems in these developing regions is the lack of technical and economic viabilities of such projects, due to low research funding and technical know-how. Thus, a lot of research funding and technical efforts are still required to massively develop renewable energy infrastructure in developing countries; and this justifies the need for this study.

Solar is among the most widely studied renewable energy sources worldwide, perhaps due to its universal availability at no cost [3,4]. It can be harnessed using two main types of technologies; concentrated solar power (CSP) and photovoltaic (PV) systems. CSP systems employ tracking mechanisms to position a set of mirrors (collectors) in the direction of the sun, for the production of thermal energy in the receiver and subsequent conversion to electricity. In PV systems, however, panels track the photonic energy of the sun for direct conversion to electricity. Although the PV technology has advanced significantly in terms of scalability and cost, it generally has lower efficiency than the CSP technology [5]. Besides, CSP projects are easily amenable for the generation of thermal energy for industrial applications, and that has made them very attractive for off-grid energy applications [6]. Many researchers have applied different computer simulation methods to study the feasibilities and applications of CSP systems for off-grid energy generation in different countries; a summary of these studies is reported hereunder.

Martin-Pomares et al. [7] applied eleven-year hourly satellite-derived solar data to analyze the long-term feasibility of solar energy generation in Qatar and obtained that a parabolic trough CSP plant with a large thermal energy storage system had a huge potential in the country. Polo et al. [8] demonstrated the long-term feasibility of CSP plants based on a multi-year statistical analysis and System Advisor Model (SAM) simulation of four power plants in the Mediterranean North African region. Sequel to the aggressive plan of the Saudi Arabian Government to integrate about 25 GW of energy from CSP plants into the national grid, Kassem et al. [9] reported from their analysis of the strength, weakness, opportunity, and threat (SWOT) of different CSP technologies that the parabolic trough is the most mature and the most commercially deployed CSP technology. Serradj et al. [10] assessed the viability of a 100 MW parabolic trough thermal power plant for the city of Tamanrasset, Algeria, and reported that such a plant could satisfy about 78% of the city's total electricity demand in winter, and about 60% in summer. Similarly, Alotaibi et al. [11] employed the SAM software to design and analyze a 100 MW parabolic trough power plant for the city of Riyadh, Saudi Arabia, and reported that about 45% capacity factor was achievable by the plant at an acceptable levelized cost of electricity (LCOE). Sharma et al. [12] equally employed the SAM software to study the effects of the direct normal irradiation (DNI), solar multiple, and capacity of storage on the levelized unit cost of electricity (LUEC) of parabolic trough and linear Fresnel collectors. They reported the range of each parameter where the LUEC is lowest for each of the CSP technologies considered. Bishoyi and Sudhakar [13] reported, based on the design and performance simulation of a 100 MW parabolic trough power plant in India, that the thermal efficiency and electricity cost obtained from the hypothetical plant is such that should encourage further studies and innovations toward the implementation of CSP plants in the country. Also, Aseri et al. [14] reported the importance of integrating high-capacity thermal energy storage systems with CSP plants with low nominal capacities, over increasing the nominal capacities of such systems without energy storage. Praveen et al. [15] reported the feasibility of CSP plants to contribute to the development of sustainable energy in the Middle East, based on the SAM-based design and performance simulation of a parabolic trough power plant in the cities of Abu Dhabi and Aswan. In another study, Praveen et al. [16] proposed a fuzzy non-linear programming model to optimize the design of parabolic trough power plants, and when applied to a 100 MW plant in India, the approach was reported to improve significantly the capacity factor and cost. Ullah et al. [17] designed and constructed a small-scale parabolic trough solar power plant based on the results of modeling and simulation where different heat transfer fluids were compared for the CSP plant. Kherbiche et al. [18] assessed the viability of solar plants for electricity generation in M'Sila, Algeria, and recommended that the parabolic trough CSP plants should be adopted for the city. Furthermore, mohammadi et al. [19] investigated the feasibility of parabolic trough solar plants for industrial heat generation and reported that a 5 Mwt plant in Utah is competitive with plants fuelled with natural gas. Hirbodi et al. [20] assessed the techno-economic and environmental performance of CSP plants in the Southern region of Iran, and reported that a 100 MW plant with an average of 14 hours of thermal energy storage and a solar multiple of 3.0 would be competitive for electricity generation in the region. Tahir et al. [21] went beyond the usual techno-economic viability assessment of CSP plants in Pakistan, to also discuss robustly the financial, technical, infrastructural, political, and other barriers that might affect the implementation of such plants, and the possible way out of such barriers. Trabelsi et al. [22] assessed the techno-economic feasibility of deploying a 50 MW parabolic trough power plant in the southern region of Tunisia. They reported that adopting the dry cooling scheme for the power plant would lead to a technically viable system for this desert region, with LCOE of about 18 ₡$/kWh.

The literature review in the foregoing clearly shows that solar projects based on the parabolic trough CSP technology are ubiquitous, albeit with economic limitations. Also, it is explicitly revealed in the review that SAM is a very vital and popular tool being used for the design and simulation of CSP systems, perhaps because it is open-source software and it is able to account for the dynamic nature of climatic parameters up to minute-by-minute variation in the simulation. While feasibility studies have been carried out for different countries of the world, information is non-existent on the techno-economic feasibility of large-scale CSP systems for electricity generation in Nigeria, despite the favorable climatic conditions in the country. To bridge this gap, this study aims to apply the SAM software to assess the viability of a 25 MW parabolic trough CSP plant for the climatic condition of Effurun-Warri, Southern Nigeria. The specific objectives of the study are:

- To design a 25 MW solar parabolic trough system using the SAM software;
- To analyze the yearly energy production profile of the 25 MW parabolic trough system based on the ambient conditions of the twin city of Effurun-Warri in Southern Nigeria; and
- To assess the techno-economic feasibility of the 25 MW CSP plant based on the current market realities in Nigeria.

Section 2 summarizes the method employed in this study; the results obtained are presented and discussed in section 3, and the main conclusions are summarized in section 4.

2. Methodology

2.1. Plant scheme and site description

Figure 1 depicts a schematic illustration of the proposed CSP plant. It is made up of a network of intertwined pipelines and an array of parabola-shaped mirrors. The pipelines are known as solar receivers, and they carry heat transfer fluid (HTF) from the collectors to the power block for conversion into electricity. The plant includes two-tank thermal energy storage (TES) system that uses molten salt as the storage medium. When solar energy is abundant, the HTF heats the storage medium in the TES for later use in electricity generation during the hours when solar irradiation is low or non-existent. In this study, the power plant is an air-cooled steam power plant that operates on the Rankine cycle.

The climatic parameters of Delta State's Uvwie Local Government Area, where Effurun-Warri is located, were obtained from the National Solar Radiation Database (NSRDB), as shown in Table 1. They validate the SAM software's built-in data for this location.

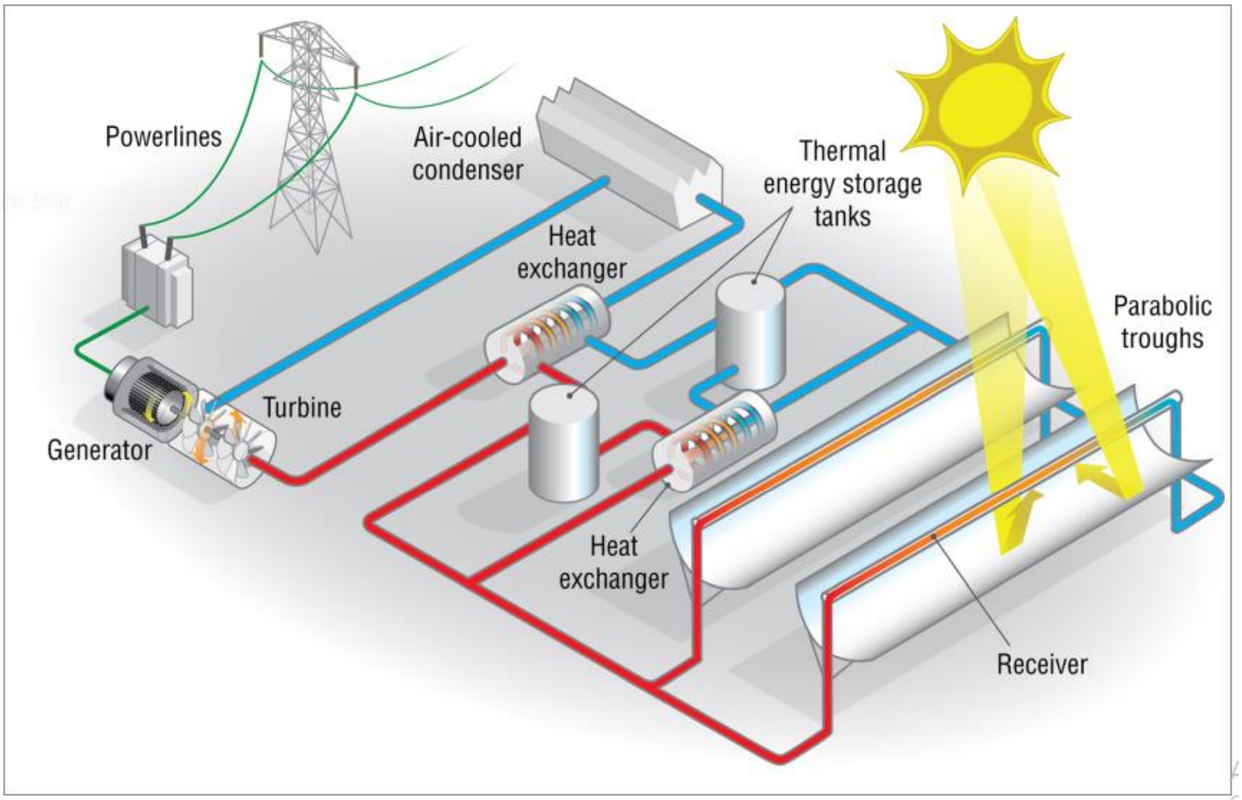

Fig. 1. Parabolic trough power plant scheme

Table 1. Climatic Parameters of Effurun-Warri, Nigeria

Parameter	Value
Latitude (^{0})	5.57
Longitude (^{0})	5.78
Tilt angle (^{0})	20
Azimuth angle (^{0})	180
Average temperature (^{0}C)	25.9
Global Horizontal Irradiation (GHI) (kWh/m^2/day)	3.39
Average wind speed (m/s)	0.4

2.2. System Advisor Model design parameters of the CSP plant

As previously stated, the SAM software [23] was used to simulate the CSP plant's techno-economic feasibility. It was originally developed by the National Renewable Energy Laboratory (NREL) in America; its source physical and financial models have been validated, making it a veritable tool in the open literature for simulation of renewable energy systems today. The power plant's design in SAM was based on a nominal direct normal irradiation (DNI) of 950 W/m2 and a solar multiple (SM) of 2. Because of its widespread use in practical systems, therminol VP-1 was chosen as the HTF. Again, molten salt is used as the storage medium in the TES system, and 6 hours of thermal energy storage was chosen for the design in the SAM software. Table 2 highlights all of the other input details for the power plant's performance simulation.

Table 2. Parabolic trough CSP plant parameters

Parameter	**Values**	**Units**
Solar multiple	2	
Field aperture	877, 000, 000	m^2
Design point DNI	950	W/m^2
Field thermal power	157	W/m^2
Loop inlet HTF temperature	293	^{o} C
Loop outlet HTF temperature	391	^{o} C
Number of loops	46	
HTF pump efficiency	0.85	
Power Cycle		
Design turbine gross output	28	MWe
Estimated gross-to-net conversion factor	0.9	
Estimated output at design	25	MWe
Cycle thermal eff.	0.356	
Cycle thermal power	76	MWt
Thermal Energy Storage		
Hours of storage at the design point	6	Hr
Tank height	12	M
Heat Transfer Field		
HTF	Therminol VP – 1	
Inflation rate	18	%/yr
Solar Field Area	149	Acres

3. Results And Discussion

3.1. Solar energy profile

The field absorbs only a fraction of the thermal power incident on the solar collectors. This is due to optical losses caused by mutual shading of collectors, row end losses, and solar field geometrical inaccuracies. Figure 2 depicts the cumulative solar thermal energy at the plant's location over the course of a typical year. The months in horizontal axis against solar radiation incident measured in megawatt (MW) in the vertical axis In Figure 2, e + 06 as generated by the System Advisor Model (SAM) software signifies mega unit (M). Hence, 4e + 06 = 4 * 10^6 = 4MW, 5e + 06 = 5 * 10^6 = 5MW, 6e + 06 = 6 * 10^6 = 6MW, 7e + 06 = 7 * 10^6 = 7MW, etc,. August had the most solar radiation incident on the solar field (10 MW), followed by September and July. February has the lowest incident thermal power on the solar field (3.98 MW).

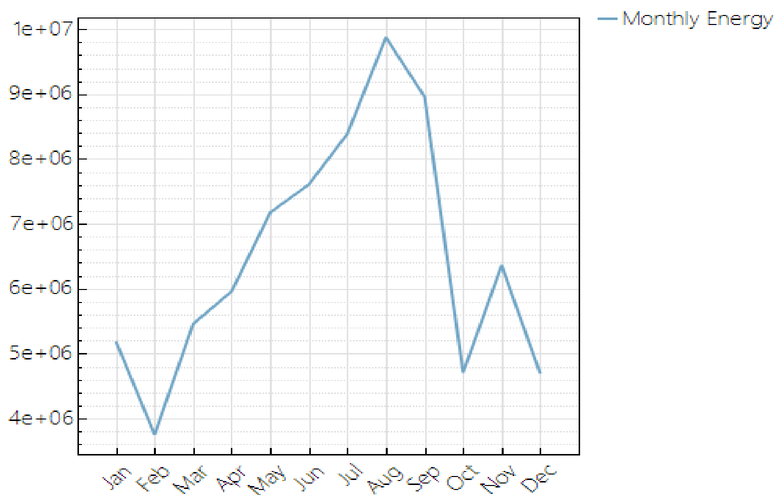

Fig. 2. Monthly solar energy profile of the CSP plant

3.2. Annual electrical energy production and techno-economic performance

The power cycle gross electrical output of the hypothetical power plant is 88.3GWh, with an annual net electrical energy production of around 78GWh. Figure 3 depicts the profile of the power plant's net electrical power output on typical Hour of Day (24hrs) in the horizontal axis in each month. The plant was designed to begin producing electrical energy when the solar field produced 25% of the nominal thermal energy required. The coldest months in Effurun are January, February, October, and December. They are also the times when the days are shorter. During these months, the power plant generates power for a total of 13 hours, with 6 hours at maximum capacity for the day (about 18.6 MW). In June, July, and August, the plant usually starts earlier and runs at full capacity for 9 hours. The months of August, June, and July have the highest annual power output.

The plant's capacity factor is 35.4%, implying that the parabolic trough power plant could contribute significantly to meeting Effurun-electricity Warri's demands. The plant would require a total land area of 1,140 m^2, which should not be a problem given the city's abundance of inhabited land. The plant consumes 19.2 MWe of parasitic power per year. The plant's solar field energy absorption efficiency is 56.2%. Furthermore, a levelized cost of electricity of 11.87 ₵/kWh was obtained for the power plant, which is 99% higher than the cost of electricity available in this part of Nigeria (0.10 ₵/kWh), however, this depreciates as plant's aged without optimizing plant's design parameters. Furthermore, a negative NPV of $-13.2 M was obtained for the proposed project, implying that the investment cost would not be completely offset over the lifetime of the system, resulting in losses to investors. Figure 4 depicts the CSP plant's detailed techno-economic performance metrics. Furthermore, the plant's annual production has been observed to depreciate as it ages, and the trends of energy production and project cash flow for the 25-year plant life assumed in this study are depicted in Fig. 5.

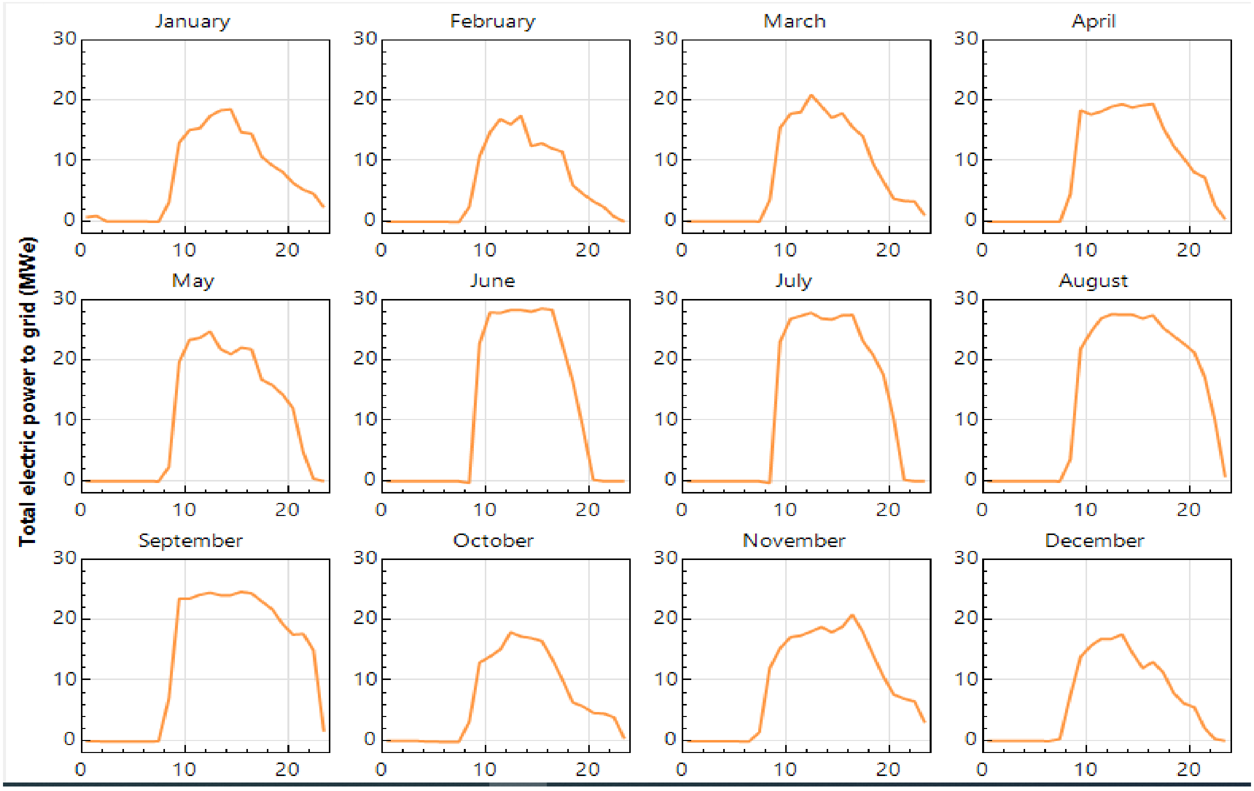

Fig. 3. Monthly electrical energy produced by the power plant

Metric	Value
Annual Net Electrical Energy Production	78,087,792 kWh-e
Annual Freeze Protection	134,488 kWh-e
Annual TES Freeze Protection	49,489 kWh-e
Annual Field Freeze Protection	84,999 kWh-e
Capacity factor	35.4%
Power cycle gross electrical output	88,313,048 kWh-e
First year kWh/kW	3,099 -
Gross-to-net conversion	88.4 %
Annual Water Usage	18,895 m^3
PPA price (year 1)	23.12 ¢/kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	32.13 ¢/kWh
Levelized PPA price (real)	10.44 ¢/kWh
Levelized COE (nominal)	36.55 ¢/kWh
Levelized COE (real)	11.87 ¢/kWh
Net present value	$-13,214,366
Internal rate of return (IRR)	11.00 %
Year IRR is achieved	6
IRR at end of project	NaN
Net capital cost	$159,613,344
Equity	$55,971,600
Size of debt	$103,641,736

Fig. 4. Techno-economic performance metrics of the parabolic trough CSP plant

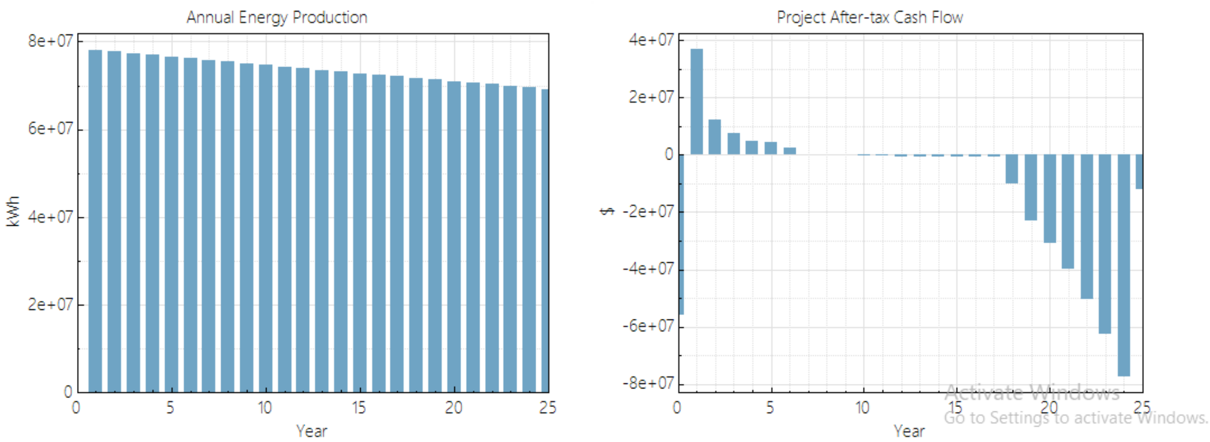

Fig. 5. Annual energy production and project cash flow over the plant life

Figure 5 show cased yearly Annual Energy Production in kWh and Project After - Cash Flow in dollar. It can be deduced from the above figure that energy production decreases as year increases and that Tax Cash Flow turns negative immediately after tenth year. This is because the plant's design parameters (Concentrated Solar Power CSP, Parabolic Trough Collectors PTC, Regional Climate Change, etc.) were not altered or optimized over these years which possibly have the capacity to retard energy production rate. The designed model competes favorably with other major parabolic trough power plants around the world. The SEGS solar plants in California's Mojave deserts, which cover a total land area of 1600 acres, have a combined rated power of 361 MW and a capacity factor of 21%. The Khata solar spark in South Africa covers an area of 1977 acres and has a rated net capacity of 100 MW with a capacity factor of 44.5 %. The Andasol solar power plant has a rated output of 150 MW, a capacity factor of 37.7 %, and a land area of 1500 acres.

Table 3. Comparative techno-economic performance results with some reviewed literatures

Author (s)	**Year**	**Work**	**Method(s)**	**Material(s)**	**Results**
Praveen et al	2022	Optimization of a 100 MW PTC plant	Fuzzy non-linear model	Parabolic Trough Collectors (PTC)	Significant improve in Capacity Factor and Cost
Polo et al	2016	Feasibility of a Long-Term operation of a CSP power plant in Saudi Arabia	System Advisor Model (SAM) software	Concentrated Solar Power (CSP)	25 GW
Serradj et al	2021	Viability of a 100MW PTC power plant in Tamanrasset, Algeria	HOMER and System Advisor Model (SAM) software	Parabolic Trough Collectors (PTC)	78 % in winter and 60 % in summer energy required
Alotaibi et al	2021	Design and analysis of a 100 MW PTC power plant in Riyadh, Saudi A rabia	System Advisor Model (SAM) software	Parabolic Trough Collectors (PTC)	45% capacity factor achievable

Table 3 Continued

Author (s)	Year	Work	Method(s)	Material(s)	Results
Sharma et al	2016	Effect of a direct normal irradiation (DNI), solar multiple and capacity storage on LUEC	System Advisor Model (SAM) software	Parabolic Trough Collectors (PTC) and Linear Fresnel Collector (LFC)	Range of lower compared to CSP
Trabelsi et al	2016	Feasibility of a 50 MW PTC plant in southern region, Tunisia	System Advisor Model (SAM) software	Parabolic Trough Collectors (PTC)	Dry cooling scheme determines viable system in Tunisia of LCOE of about 18₵$ /kWh
Pareen et al	2018	Feasibility of CSP power plant in Middle East	System Advisor Model (SAM) software	Concentrated Solar Power (CSP)	Feasibility of CSP power plant in Middle East
John Akpaduado, Joseph Oyekale	**2021**	**Feasibility Of A Large-Scale Ptc Thermal Power Plant In Effurun-Warri, Nigeria**	**System Advisor Model (Sam) Software**	**Ptc Power Plant, Hours Per Day Consideration**	**78 Gwh Net Electricity Energy, 35.4 % Capacity Factor, 11.87₵ /Kwh, And 0.10 ₵ /Kwh**

4. Conclusions

This study evaluated the techno-economic viability of a 25 MW parabolic trough solar thermal power plant for electricity generation in Effurun-Warri, Nigeria. For the evaluation, the technical and financial models built into the System Advisor Model (SAM) software were used. The city's meteorological data were also generated by SAM and confirmed by the National Solar Radiation Database (NSRDB). The following are the main study highlights:

- The plant's annual net electrical energy production was estimated to be around 78 GWh;
- The parabolic trough solar power plant can operate for more than 12 hours per day, resulting in a capacity factor of 35.4 %;
- The power plant's LCOE was 11.87 ₵/kWh, compared to the current cost of energy in Nigeria is 0.10 ₵/kWh, with a negative NPV, indicating an unprofitable investment.

It is recommended that the plant's design parameters be optimized using comparative analysis, and that further feasibility studies of CSP projects in Nigeria be conducted taking into account the country's various climatic regions.

References

[1] Moreno-monroy, A.I., Schiavina, M., Veneri, P., "Metropolitan areas in the world . Delineation and population trends", *J. Urban Econ.*, *125*, 103242, 2021, doi:10.1016/j.jue.2020.103242.

[2] Tartière, T., Astolfi, M. A, "World Overview of the Organic Rankine Cycle Market", *Energy Procedia*, *129*, 2–9, 2017 doi:10.1016/j.egypro.2017.09.159.

[3] Hasan, A., Sarwar, J., Shah, A.H., "Concentrated photovoltaic: A review of thermal aspects, challenges and opportunities", *Renew. Sustain. Energy Rev. 94*, 835–852, 2018, doi:10.1016/j.rser.2018.06.014.

[4] Gauché, P., Rudman, J., Mabaso, M., Landman, W.A., von Backström, T.W., Brent, A.C., "System value and progress of CSP", *Sol. Energy, 152*, 106–139, 2017 doi:10.1016/j.solener.2017.03.072.

[5] Torres, G. de S., de Oliveira, T.A.P., Filho, A. de L.F., Melo, F.C.; Domingues, E.G. "Techno-economic assessment of concentrated solar and photovoltaic power plants in Brazil", *Renew. Energy Power Qual. J.*, *19*, 583–588, 2021doi:10.24084/repqj19.353.

[6] Răboacă, M.S., Badea, G., Enache, A., Filote, C.; Răsoi, G., Rata, M., Lavric, A., Felseghi, R.-A. "Concentrating Solar Power Technologies", *Energies*, *12*, 1048, 2019 doi:10.3390/en12061048.

[7] Martín-Pomares, L., Martínez, D., Polo, J., Perez-Astudillo, D., Bachour, D., Sanfilippo, A. "Analysis of the long-term solar potential for electricity generation in Qatar", *Renew. Sustain. Energy Rev. 73*, 1231–1246, 2017, doi:10.1016/j.rser.2017.01.125.

[8] Polo, J., Téllez, F.M., Tapia, C. "Comparative analysis of long-term solar resource and CSP production for bankability", *Renew. Energy*, *90*, 38–45, 2016 doi:10.1016/j.renene.2015.12.057.

[9] Kassem, A., Al-Haddad, K., Komljenovic, D. "Concentrated solar thermal power in Saudi Arabia: Definition and simulation of alternative scenarios", *Renew. Sustain. Energy Rev.*, *80*, 75–91, 2017, doi:10.1016/j.rser.2017.05.157.

[10] Benhadji Serradj, D.E., Sebitosi, A.B., Fadlallah, S.O. "Design and performance analysis of a parabolic trough power plant under the climatological conditions of Tamanrasset, Algeria", *Int. J. Environ. Sci. Technol. 2021*, 2021, doi:10.1007/s13762-021-03350-x.

[11] Alotaibi, H.M., Al-Kouz, W., Boretti, A., "Design of a 100 MW Concentrated Solar Power Plant Parabolic Trough in Riyadh, Saudi Arabia". *E3S Web Conf.*, *242*, 2021 doi:10.1051/e3sconf/202124201001.

[12] Sharma, C., Sharma, A.K., Mullick, S.C., Kandpal, T.C., "A study of the effect of design parameters on the performance of linear solar concentrator based thermal power plants in India", *Renew. Energy*, *87*, 666–675, 2016 doi:10.1016/j.renene.2015.11.007.

[13] Bishoyi, D., Sudhakar, K. "Modeling and performance simulation of 100 MW PTC based solar thermal power plant in Udaipur India". *Case Stud. Therm. Eng.*, *10*, 216–226, 2017 doi:10.1016/j.csite.2017.05.005.

[14] Aseri, T.K., Sharma, C., Kandpal, T.C. "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, 2022 doi:10.1016/j.est.2022.103976.

[15] Praveen, R.P., Baseer, M.A., Awan, A.B., Zubair, M. "Performance analysis and optimization of a parabolic trough solar power plant in the middle east region". *Energies*, *11*, 1–18, 2018 doi:10.3390/en11040741.

[16] Praveen, R.P., Chandra Mouli, K.V.V. "Performance enhancement of parabolic trough collector solar thermal power plants with thermal energy storage capability" *Ain Shams Eng. J.*, *13*, 101716, 2022 doi:10.1016/j.asej.2022.101716.

[17] Ullah, A., Mushtaq, A., Qamar, R.A., Ali, Z.U. "Performance analysis and modeling of parabolic trough based concentrated solar facility using different thermal fluid mediums". *J. Eng. Res.*, *9*, 13–50, 2021 doi:10.36909/JER.V9I1.8605.

[18] Kherbiche, Y., Ihaddadene, N., Ihaddadene, R., Hadji, F., Mohamed, J., Beghidja, A.H. "Solar Energy Potential Evaluation. Case of Study: M'Sila, an Algerian Province". *Int. J. Sustain. Dev. Plan.*, *16*, 1501–1508, 2021 doi:10.18280/ijsdp.160811.

[19] Mohammadi, K., Khanmohammadi, S., Immonen, J., Powell, K. "Techno-economic analysis and environmental benefits of solar industrial process heating based on parabolic trough collectors". *Sustain. Energy Technol. Assessments*, *47*, 101412, 2021 doi:10.1016/j.seta.2021.101412.

[20] Hirbodi, K., Enjavi-Arsanjani, M., Yaghoubi, M. "Techno-economic assessment and environmental impact of concentrating solar power plants in Iran." *Renew. Sustain. Energy Rev.*, *120*, 109642, 2020 doi:10.1016/j.rser.2019.109642.

[21] Tahir, S., Ahmad, M., Abd-ur-Rehman, H.M., Shakir, S. "Techno-economic assessment of concentrated solar thermal power generation and potential barriers in its deployment in Pakistan". *J. Clean. Prod.*, *293*, 2021 doi:10.1016/j.jclepro.2021.126125.

[22] Trabelsi, S.E., Chargui, R., Qoaider, L., Liqreina, A., Guizani, A.A. "Techno-economic performance of concentrating solar power plants under the climatic conditions of the southern region of Tunisia." *Energy Convers. Manag.*, *119*, 203–214, 2016 doi:10.1016/j.enconman.2016.04.033.

[23] Home - System Advisor Model (SAM) Available online: https://sam.nrel.gov/ (accessed on Feb 19, 2022).