



## Development of 20MW Concentrated Solar Power System in Nigeria using System Advisor Model

Abdulkarim Mayere  
Centre for Energy and Environmental Strategy Research  
Kaduna State University

### ABSTRACT

Solar energy electricity generation, in the form of concentrating solar power (CSP), is a proven renewable energy technology with the potential to compete with other forms of electricity generation technology, including fossil fuels. Some regions in Nigeria are ideally located to support the CSP technology. A design for 20MW CSP plant is presented using the System Advisor Model (SAM). A total of 2,964 heliostats are required covering 336,633 m<sup>2</sup>. The design shows the potential to reach a Levelized Cost of Electricity (LCOE) value of 0.13 \$/kWh.

### ARTICLE INFO

Article History

Received: November, 2022

Received in revised form: February, 2023

Accepted: March, 2023

Published online: March, 2023

### KEYWORDS

Keywords Solar Thermal, Power Tower, heliostats

### INTRODUCTION

Nigeria is home to an estimated 195 million people constituting 36 states. The Human Development Index (HDI) of the United Nations Development Program (UNDP) ranks various countries in the world based on their level of human development. Education, life expectancy and Gross National Income per capita (GNI) are the primary sources of data for the indexing. Sub-Saharan Africa has the least HDI value in all regions with Nigeria ranked a poor 157 out of the 189 ranked countries [1]. An estimated 65% of the population live in rural communities. The rural access to electricity is among the poorest in the world at 22.6% [2]. Most of the rural communities are not even connected to the national grid due to the high cost associated with it. With all these figures and data, it is easy to see the correlation between poverty and energy. Emphasis must be put on the provision of proven sustainable energy in those regions.

Specialists often append the power sector in Nigeria as one of the critical constraints to the economic

development in the region. Assessing the ease of getting electricity, the World Bank ranked Nigeria 146 of 190 countries in the Doing Business report of 2019 [3]. Once connected to the electricity provider, the erratic power supply remains a constant feature. Power failures experienced in the year 2000 alone led to power rationing and this, in turn, profoundly affected their economies and development [4]. In a bid to improve the reliability and stability of electricity, the government privatised the electricity sector in the year 2013.

Renewable energy technologies, and in particular solar energy, have great promise in Nigeria and could potentially meet all the energy demands in the region. However, most of that potential is either underexploited primarily due to poorly integrated structures, weak policies and planning, and technical and financial reasons or improper implementation.

Solar energy can be harnessed through solar photovoltaic technologies or through solar thermal technologies. Solar thermal energy for

Corresponding author: Abdulkarim Mayere

✉ [al.mayere@kasu.edu.ng](mailto:al.mayere@kasu.edu.ng)

Centre for Energy and Environmental Strategy Research.

© 2023. Faculty of Tech. Education, ATBU Bauchi. All rights reserved

electricity generation is typically referred to as Concentrated Solar Power (CSP) [5]. In this paper, the emphasis is given to solar thermal electricity. CSP can be a driving force in the cause of reducing CO<sub>2</sub> emission for Nigeria, thereby contributing to reducing and limiting the global temperature increase in addition to providing a potential solution to the deplorable energy situation in the country.

## CONCENTRATED SOLAR POWER SYSTEMS

Concentrated Solar Power (CSP) utilizes mirrors to concentrate the beam radiation from the sun onto an absorber or receiver which hold and heats up the solid, liquid or gas that is subsequently used directly or indirectly to power turbines for electricity generation. Figure 1 shows the basic operational principle.

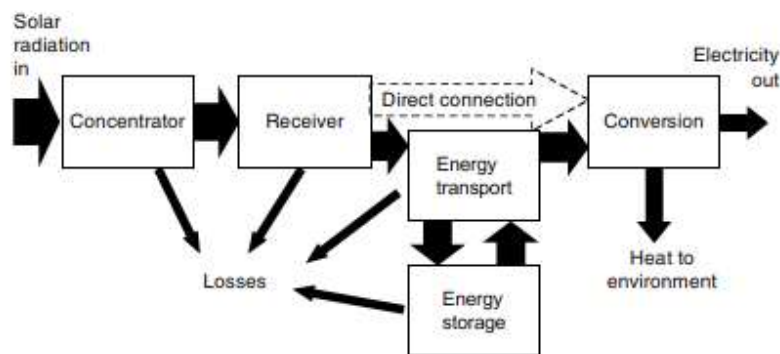


Figure 1. Basic operational principles of the CSP system

The operational principles of concentrating power have been known for over a century. However, commercial production only began in the 1980s [6]. Several technologies are used to concentrate and collect sunlight and to turn it into medium to high-temperature heat which could be stored can then, in turn, be converted into electricity. The heat can also be stored, which could be extracted at night from the storage medium to drive the turbine when there isn't any sunshine. CSP technologies continue to mature and are being deployed worldwide.

Generally, CSPs can be broken down into 2 categories; Point and Line Focusing CSP systems. Line focusing systems include; Linear Fresnel and Parabolic trough system. Point

Focusing Systems include; power tower system and the parabolic dish system [7]. The four types of CSPs are presented as follows;

### Dish/Engine Systems

Dish/Engine systems are small units that produce electricity typically in a small range of ten of kW or even smaller. The dish system offers the highest transformation of any CSP system [8]. The system utilizes dishes of mirrors that reflect sunlight onto a thermal receiver and a central engine which produces electricity. Dish engine systems are capable of tracking the sun in two-axes. The engine placed at the focal point is typically sterling or a small gas turbine. [9]

### **Linear Concentrating Systems-Parabolic trough**

Linear concentrating collectors capture the sun's energy with parabolic shaped mirrors that reflect and focus the sunlight onto an absorber tube placed along the focal line of the parabolic reflective material. The receiver contains a fluid, Heat Transfer Fluid (HTF) that is heated by the sunlight and transfers energy to conventional steam cycle to produce superheated steam which powers a turbine that drives a generator to produce electricity. The fields typically consist of a large number of collectors in parallel rows that are aligned to track the sun in one axis to optimize energy collection.

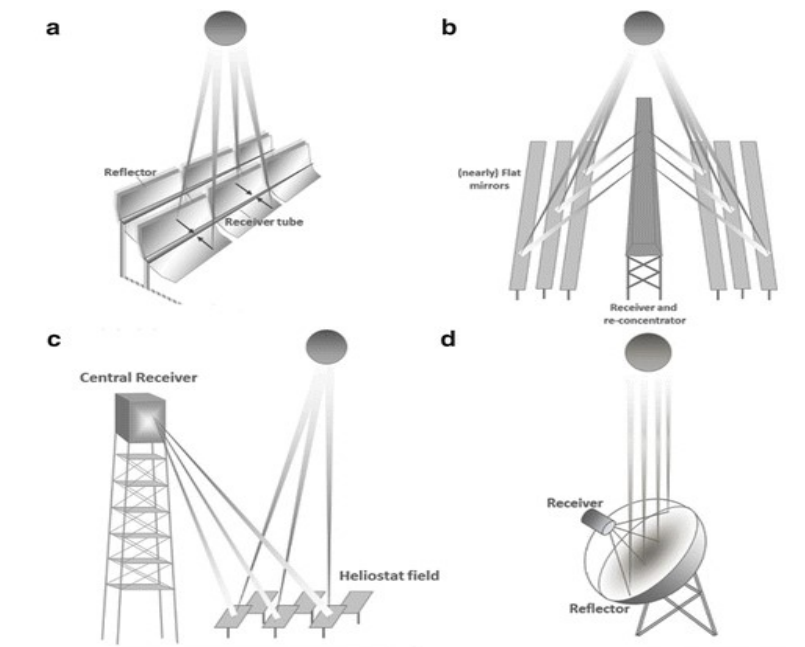
### **Power Tower Systems**

Power tower systems use large distributed tracking mirrors (heliostats) that concentrate the beam

radiation onto a receiver atop a centrally located tower. A very high temperature of up to 1000 °C is achievable in this kind of system [10]. The concentrated solar energy is absorbed by the working fluid, which produces the steam used in powering a turbine to produce electricity [11].

### **Linear Fresnel System**

Linear Fresnel system is very much alike to the parabolic trough system. However, in place of the parabolic reflector, almost flat linear mirror strips are being utilized which reflect radiation onto a fixed receiver mounted over on top of the mirrors [6]. The nature of the mirrors utilized here makes it considerably cheaper than other technologies to make and the fact that they do not need much structural support as they are mounted close to the ground. [5]



**Figure 3: a) Parabolic dish b) Linear Fresnel c) Power Tower d) Dish system - [12]**

Corresponding author: Abdulkarim Mayere

✉ [al.mayere@kasu.edu.ng](mailto:al.mayere@kasu.edu.ng)

Centre for Energy and Environmental Strategy Research.

© 2023. Faculty of Tech. Education, ATBU Bauchi. All rights reserved

## SYSTEM DESIGN

Amongst all the different CSP technologies, power tower systems are considered to be one of the most promising. This is mainly because of their ability to offer higher temperatures and hence higher efficiencies. In addition, power towers can readily integrate thermal energy storage into their operation, providing higher capacity factors, which can potentially provide for cost-effective, dispatchable electricity capable of serving immediate and base-load power markets [13, 14, 15].

In order to provide an insight into the potential of CSP systems in Nigeria, a 19.9MWe demonstration Power Tower Plant is hence designed using the System Advisor Model (SAM). SAM is a performance and financial model developed by the

National Renewable Energy Laboratory (NREL) targeted for people in the renewable energy industry field. In the solar power tower model of the tool, SAM is capable of optimizing the heliostat field by using computational efficient Hermite expansion technique applied each heliostat image. The field design optimization strategy is based on six steps, as highlighted in the user help manual [16]. The strategy revolves around initially forming an oversized radial staggered field before progressively removing the worst-performing fields based on cosine, intercept, attenuation, reflectance and blocking field energy losses.

The following details in Table 1 and assumptions are made in the course of the design:

**Table 1:** SAM input values

Parameter	Value
Location	Nigeria (Lat. 12°.393', Long. 7°.496')
Heliostat Area	115.246 m <sup>2</sup>
Receiver Area	257.56 m <sup>2</sup>
Heat Transfer Fluid (HTF) Outlet Temp.	565 °C
Solar multiple	2.5
Tower Height	105.407
Turbine Power (Gross)s	19.9 MW
Turbine Power (Net)	17 MW
Condenser Type	Evaporative
Thermal Energy Storage (Full Load Hours)	15 Hrs

## RESULTS

Figure 2 shows the layout of the field as generated by SAM. A total of 2964 heliostats are required to

produce a gross turbine output of 19.9MW. The details of the results are detailed in Table 2.

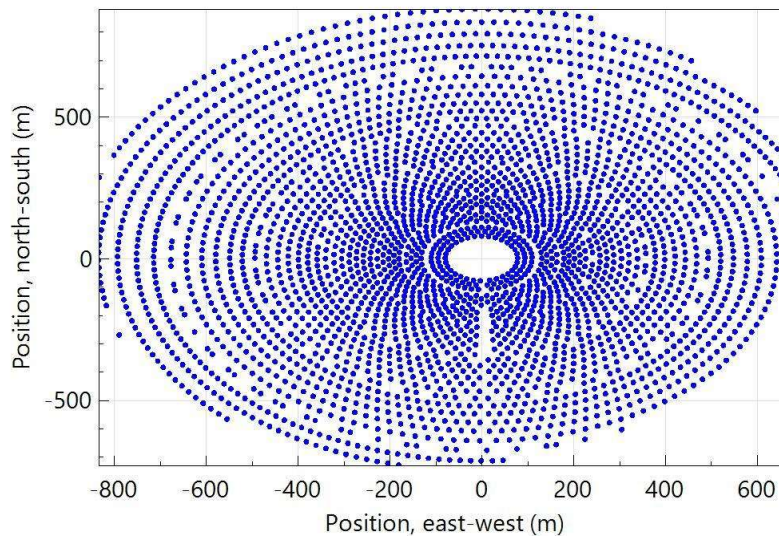


Figure 2: 20 MW Heliostat field layout

Table 2. SAM output values

Parameter	Value
Annual Energy	118,010,064 kWh
Capacity Factor	77.4%
Total Installed Cost	\$ 178,423,000
Average Annual Field Efficiency	56.91%
Total Land Area	478.51 acres
Total Reflective Surface Area	336,633 m <sup>2</sup>
Nomial Levelized Cost of Electricity (LCOE)	0.131 \$/kWh

Although the LCOE is higher than the average cost of gas and hydropower electricity generation estimated in Nigeria to be between 0.05 to 0.1 \$/kWh [17], cost reductions for CSP is expected to continue to fall beyond the year 2020 to a range between 0.06 to 0.10 \$/kWh [18]. According to the National Renewable Energy Laboratory (NREL) Annual Technology Baseline, the LCOE of natural gas, coal and nuclear is expected to hold steady or even increase [19] thereby potentially making CSP competitive with other forms of electricity generation.

## CONCLUSION

Due to the declining patronage on nuclear energy and volatile petroleum and natural gas prices, coupled with the rising global temperature predominately as a result of the atmospheric build-up of CO<sub>2</sub>, nations at large are opting and considering renewable energy technologies for their power generation. Solar energy, in particular, is seen as an extremely viable option, especially in areas with good solar insolation.

The power sector in Nigeria is one of the critical constraints to economic development in the region.



The erratic power supply remains a constant feature. Given the geographical location of some regions, solar energy electricity generation in the form of Concentrated Solar Power (CSP) could potentially be a viable and promising option for Nigeria in combating climate change and providing energy security. Given the enormous potential of CSP systems, the country needs to establish further regulations specific to CSP and offer incentives for investors, both local and foreign so that the technology may be taken up in the soonest.

The design of a 19.9MWe power tower CSP plant shows the potential to reach a Levelized Cost of Electricity (LCOE) value of 0.13 \$/kWh. Cost reductions in CSP technologies are expected to continue to fall beyond the year 2020 due to market growth and increased mass production. Also, the possibility of a large scale inclusion of storage further increases the advantages of the technology.

## REFERENCES

- [1] UNDP. Human Development Indices and Indicators: 2018 Statistical Update. 2018.
- [2] The World Bank. The World Bank Data- Nigeria. Available at: <https://data.worldbank.org/country/nigeria> (Accessed: 8 October 2019)
- [3] WB. Doing Business 2019: Training for Reform. World Bank. 2019, 304. Available at: DOI: 10.1596/978-1-4648-1326-9
- [4] The World Bank. World Development Report 2011. Washington DC; 2011.
- [5] IEA. Technology Roadmap Solar Thermal Electricity. International Energy Agency (IEA). 2014; 52. Available at: DOI: 10.1007/SpringerReference\_7300
- [6] Estela., Greenpeace, SolarPACES. Solar Thermal Electricity - Global Outlook 2016. 2016: 114.
- [7] Behar O., Khellaf A., Mohammedi K. A review of studies on central receiver solar thermal power plants. *Renewable and Sustainable Energy Reviews*. Elsevier; 2013; 23: 12–39. Available at: DOI:10.1016/j.rser.2013.02.017
- [8] Zhang HL., Baeyens J., Degève J., Cacères G. Concentrated solar power plants: Review and design methodology. *Renewable and Sustainable Energy Reviews*. 2013; 22: 466–481. Available at: DOI:10.1016/j.rser.2013.01.032
- [9] Kalogirou SA. Solar thermal collectors and applications. *Progress in Energy and Combustion Science*. 2004. 231–295 p. Available at: DOI:10.1016/j.pecs.2004.02.001
- [10] IRENA. Renewable Energy Technologies Cost Analysis Series: Concentrating Solar Power. *Comprehensive Renewable Energy*. 2012; 3(2): 595–636. Available at: DOI:10.1016/B978-0-08-087872-0.00319-X
- [11] Fritsch A., Flesch J., Geza V., Singer C., Uhlig R., Hoffschmidt B. Conceptual Study of Central Receiver Systems with Liquid Metals as Efficient Heat Transfer Fluids. *Energy Procedia*. Elsevier B.V.; 2015; 69(0): 644–653. Available at: DOI:10.1016/j.egypro.2015.03.074
- [12] Konstandopoulos AG., Pagkoura C., Dimitrakis DA., Lorentzou S., Karagiannakis GP. Solar Hydrogen Production. Springer, Dordrecht; 2015. pp. 283–311. Available at: DOI: 10.1007/978-94-017-7330-0\_10 (Accessed: 14 October 2019)

Corresponding author: Abdulkarim Mayere

✉ [al.mayere@kasu.edu.ng](mailto:al.mayere@kasu.edu.ng)

Centre for Energy and Environmental Strategy Research.

© 2023. Faculty of Tech. Education, ATBU Bauchi. All rights reserved



- [13] Mills D. Advances in solar thermal electricity technology. *Solar Energy*. 2004; 76(1-3): 19-31. Available at: DOI:10.1016/S0038-092X(03)00102-6
- [14] Weinrebe G., von Reeken F., Wöhrbach M., Plaz T., Göcke V., Balz M. Towards Holistic Power Tower System Optimization. *Energy Procedia*. Elsevier; 2014; 49: 1573-1581. Available at: DOI:10.1016/j.egypro.2014.03.166
- [15] Kolb G., Ho C., Mancini T., Gary J. Power tower technology roadmap and cost reduction plan. SAND2011-2419, Sandia .... 2011; (April): 38. Available at: DOI:10.2172/1011644
- [16] NREL. System Advisor Model (SAM). NREL; 2014.
- [17] Maria Yetano Roche. True Cost of Electricity - Comparison of Costs of Electricity Generation in Nigeria. Abuja: Nigerian Economic Summit Group; Heinrich Böll Stiftung Nigeria; 2017.
- [18] Kost C., Schlegl T., Thomsen J., Nold S., Mayer J., Hartmann N., et al. Fraunhofer ISE: Levelized Cost of Electricity - Renewable Energy Technologies, March 2018. Fraunhofer ISE: Levelized Cost of Electricity - Renewable Energy Technologies., 2018; (March).
- [19] NREL. 2017 ATB. 2017. Available at: <https://atb.nrel.gov/electricity/2017/index.html?t=in> (Accessed: 15 October 2019)

---

Corresponding author: Abdulkarim Mayere

✉ [al.mayere@kasu.edu.ng](mailto:al.mayere@kasu.edu.ng)

Centre for Energy and Environmental Strategy Research.

© 2023. Faculty of Tech. Education, ATBU Bauchi. All rights reserved