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ELECTRICITY POTENTIAL AND ECONOMIC VIABILITY FOR SOLAR THERMAL PLANT IN GHANA

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Abstract

The electricity crisis in Ghana has become so problematic, that increases the country's economic growth, and reduces Nation's development growth. This decline in industrial activities, and income losses, and has brought electricity discrimination power-outages in Ghana. The paper analyzed the technical and economic performance of the solar thermal plant system based on solar energy potentials for the consumer in Ghana and assess all the financial viability for the facility. The study explored RET Screen tools to optimize to meet Ghana's electricity demand based on available energy resources and technologies. The study proposed a 3000 MW power supply nearly to the central grid of 50% power factor for 20years project life. The results showed that 13140MWh power would be exported to the central grid of the 10065 million dollars the Greenhouse Gas GHG emission reduction was 5.5 million tCO2, and the total initial cost for the project estimated to 754 million Dollars, and if the country can afford this development the electricity discriminations power outages could be solved.

Keywords: Electricity Potential, Economic Viability, Solar Thermal, Discriminations Outages, Central Grid

1. Introduction

The energy crisis has become a challenge in Ghana, reducing the country's economic fortune and growth, leading to the retardation of national developmental transformation. The decline in industrial activity, job and income losses, and interruptions are now seeming like a drag on Ghana's development agenda [1]. The study has committed itself to design solar thermal power to reverse the challenges. The aim is to analyze the solar thermal power system's technical and economic performance based on solar energy potentials for the domestic consumer in Ghana and assess all the facility's financial viability. It was not possible to explicitly determine the development of fossil fuel prices into the future, considering historical price fluctuations. Also, the investment cost of energy technologies is site-specific, thus using average values may not fully represent the cost at a location. Therefore, these cost results should be interpreted with caution and should not be considered as the exact cost values for the scenarios. The results provided are a useful benchmark for analyzing the possible generation pathways. Further studies need to be conducted to assess the impact of possible penetration of renewable generation technologies for Ghana's power generation.

1.1. Thermal energy storage (TES)

The ability of CSP to include storage at the point of power generation for delivery period extension is a distinguishing feature of CSP among other renewable technologies. Thermal energy storage (TES) can be used with solar power plants to handle the intermittencies of solar availability [2]. Normally the capacity of thermal energy storage is in the range of several hours in which it is filled with HTF during the day and emptied after sunset to maintain electricity production even after sunset. The thermal energy collected by the solar field is used by the power block to generate steam by using a heat exchanger. The power block normally used in solar power plants is a regenerative Rankin cycle which uses a steam turbine generator to produce electrical energy [3]. "Feasibility study of solar thermal electric-power generation in northern Ghana "by [4]. Again, it shows that the system can be financially viable if there is a judicious mix of major capital subsidies and modest feed-in tariffs in the hope that Central Receiver System (CRS) cost would drop significantly. Analysis with RETScreen software shows that if there is no capital subsidy or grant; at a capital cost of US $3600/kW, the plant becomes financially viable at a feed-in tariff of 40 US Cents or more[5]. Most of the studies have used techno-economic modeling for the evaluation of new CSP systems. In most cases the focus of these studies has been on the modeling of the Heat Transfer freed (HTF) of the system, often validated against experimental data, and not on its impact at power plant level [6]. The research gab this thesis seeks to fill is the techno-economic and environmental impact of Solar Thermal Power systems for Ghanaian context. In these analyses of Livelises LCOE and other financial indicators are introduced. Moreover, in this thesis the techno-economic tool is used to introduce, and to evaluate, for the first time new Thermal Energy Storage (TES) components. This study presents a technical design, economic and environmental assessment for installation of solar thermal power systems for (Centra Region) in Ghana.

1.2. Types of Thermal Energy Storage

Thermal Energy Storage options for CSP plants fall into three general categories: sensible, latent, and thermo chemical storage. A book published in the mid1980s provides a comprehensive survey of the fundamentals of the storage options, examples of systems, and the issues that must be addressed for technologies in the range from low to high temperatures. The TES operates with multiple hours of storage is the sensible, two-tank, molten-salt system. This system is used because the components associated with molten-salt handling-pumps, valves, tanks, and heat exchangers have reliable operation at commercial scale. The size of a TES for delivery period extension will be of similar size (3 to 12 hours of full load). However, the purpose is to extend the period of power plant operation with solar energy. This TES increases the solar fraction and requires larger solar fields than a system without storage [7].

1.3. Performance assessment

The performance of a Solar system is examined using selected performance in-dices such as energy output and capacity factor. Energy output is the amount of alternating current, (AC) energy by the system over a given period, demonstrated by eq1

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$$\mathbf{E}_{AC} = \sum_{t=1}^{N} E_{AC}\,,\mathrm{t} \qquad \textbf{(Eq1)}$$

where Cf is the capacity factor, AC is energy produced by the Pv Solar thermal power system and t is the entire period for the operating.

Cf is defined as the ratio of AC energy produced by the solar thermal power system over a given period to the energy output that would have been generated if the system were operating at full capacity for the entire period [8].

$$C_f = \frac{E_{ac}}{P_{pv,rated} * A_m} \qquad \textbf{(Eq2)}$$

1.4. Economic assessment and Model

The economic aspect focuses and the costs and benefits analysis of the system. The cost includes the investment cost, operation and maintenance costs, economic life of the system components, site specific economic parameters such as interest and inflation rate, site electricity price and governments policy issues. The economic performance indicators such as levelized cost of energy (LCOE), Net present value (NPV), internal rate of return (IRR), payback time (PB) and cash flow analysis. The Annualized capital Cost (Ca) is given by the product of the total cost of all components, Ci, and the capital recovery factor, CRF, which depends on the real discount rate, i and the payment period (in years), n, expressed in the equation Eq3 and Eq4 [2].

$$\mathbf{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad \textbf{(Eq3)}$$

$$\mathbf{Ca = Ci * CRF} \qquad \textbf{(Eq4)}$$

Where CRF is the Capital recovery factor, Ca is the Annualized capital cost, i is the discount rate, Ci is the total Cost of the components, and n is the payment period (in years).

The levelized cost of energy (LCOE) is a widely adopted economic index to assess the economic feasibility of Renewable Energy systems. The LCOE represents the price at which electricity must be generated from a specific source to break even over the lifetime of a project. For an annual economic analysis of the system, LCOE is defined as the ratio of sum of the total

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annualized investment cost (Ca) and the annualized operation and maintenance (O&M) cost to the annualized generated energy (Ea.) expressed by Eq5 [9].

$$\mathbf{LCOE} = \frac{Ca + O\&M}{Ea} \qquad \mathbf{(Eq5)}$$

Where LCOE is the Levelized Cost, O&M is the operation and maintenance cost, Ea is the energy generated, and Ca is the annualized investment cost.

The payback period (PB) compares the revenue with investment costs to determine how long time required to recoup an initial investment. The ratio of total investment cost, Ci to the annual return from the generated (LCOE and Ea.) energy expressed in Eq6 below

$$\text{PB} = \frac{Ci}{LCOE * Ea} \qquad \text{(Eq6)}$$

2.1. The proposed Facility

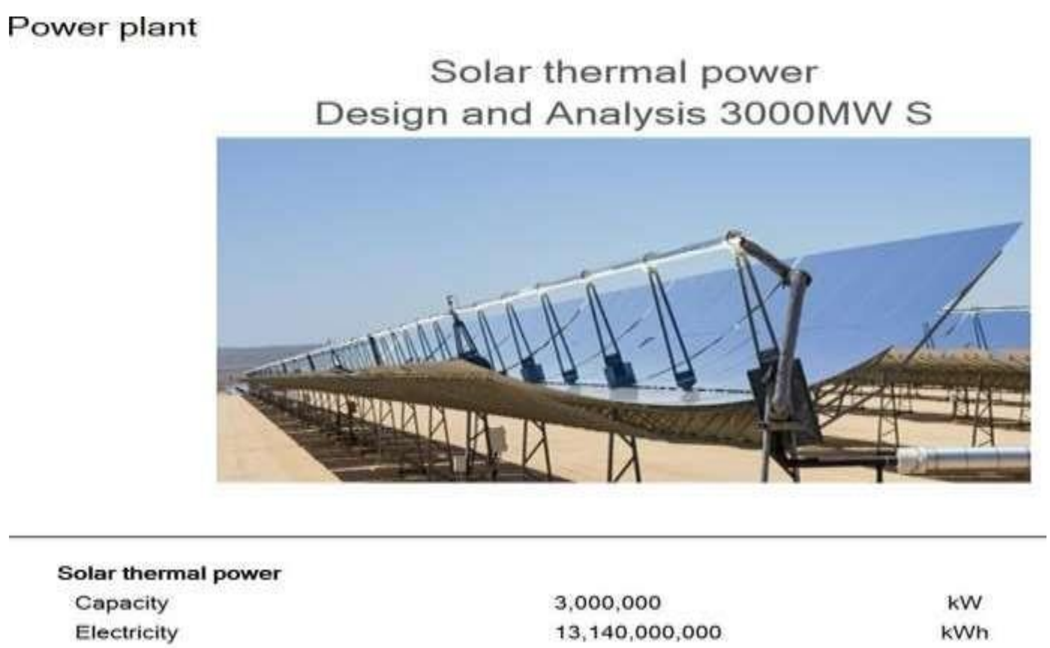

Figure 1. The propose solar power facility.

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2.2 Benchmark

Power plants provide benchmark data for various types of power plants. The database displays a range of typical minimum and maximum energy production costs (also called the Levelized Cost of Electricity or LCOE) for different types of power generation technologies under a variety of operating conditions, installation, and operation costs for typical power plants. Energy production costs include installation and operating costs. Key assumptions used to calculate the minimum and maximum range of values are also pro-vided, including the power capacity, size of the installation, as well as the fuel cost rate (for combustion power systems), or the capacity factor (for intermittent renewable energy power systems). The study assumptions of inflation rate dis-played at the bottom half of figure 2.

Energy production cost -Central -grid -Rang ($⁄MWh

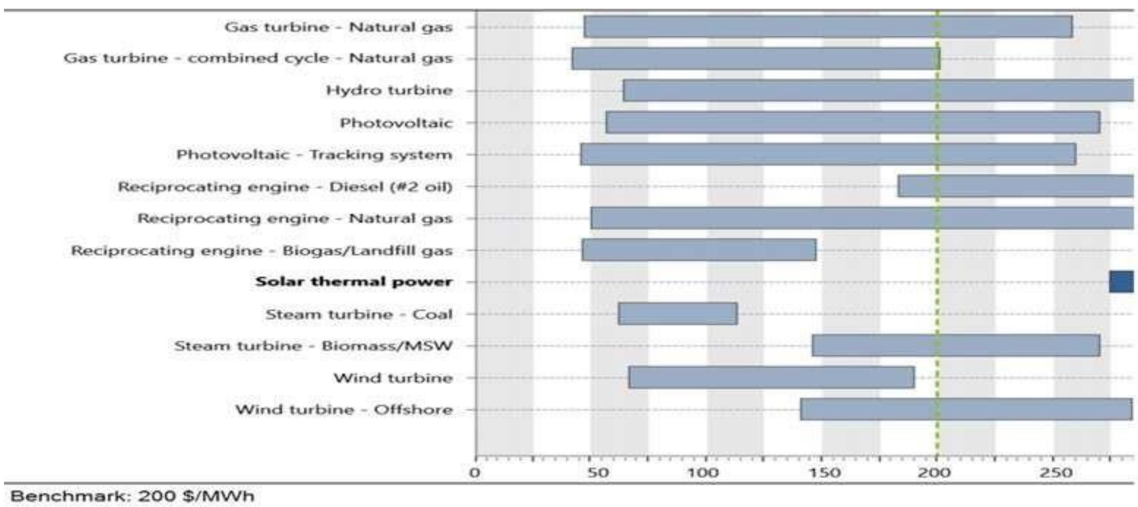

Figure 2. The benchmark for the project

2.3 Site for the Project

The site is located on the Cape Coast, Central Region of Ghana, approximately 3 km from Municipal Assembly. The site is a 5.5 km2 level hill, steep, and series of falls dropping approximately 110m. A maximum tidal range of 100 m is accommodated. The concrete storage approximately 2 m high and 120 m long would be needed to construct. In the reconnaissance survey, it was determined that a 400 m2 powerhouse, containing a single Francis turbine and a generator with a rated output of 3000MW at 50 power factors would be built at the base of the falls. A 600 m long tunnel and a 50 m long, 2 m diameter steel penstock for the conveyance to the powerhouse would be required. The structure would be constructed on the transparent hill mountain land to enable easily sun concentrated radiation located in figure 3.

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Figure.3 Location for the Facility.

Table1. Location Data at - cape coast

	Unit	Climate data location	Facility location
Latitude	N	5.1	5.1
Longitude	E	-1.3	-1.3
Climate		1A-very hot-	1A-very hot-
zone	M	Humid61	H61
Elevation			

The climate data

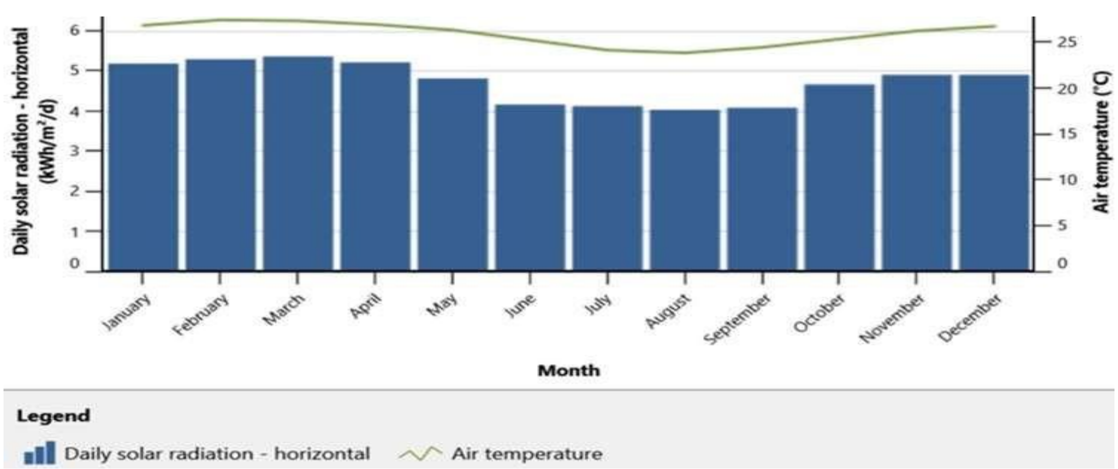

Figure 4. The Climate Data

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3. Results of Financial Viability

The financial viability analysis provided a firm income tax rate of 43.6% inflation at 2%, a debt ratio of 70% the debt interest rate of 7%, a discount rate of 10%, and a debt term of 20 years as to assume that the price paid by the utility would increase by 3% annually, the capital cost of the Project would depreciate using a straight-line method over the life of the Electricity Purchase Agreement. The Project is assumed to have a design life of 20 years. Operation & Maintenance (O&M) costs would be signed and include a full-time live-in operator. The initial cost of 754 million dollars was estimated property taxes on the 57.9Million dollars on debt term of 15 years would be 0.8% of the constructed. The RETScreen analyzed all the aspects of the financial parameters shows in Table 2 below.

Table 2. Financial Parameters

	Financial Parameters	
Inflation Rate	**%**	**2**
Project life	**Year**	**15**
Debt ratio	**%**	**70**
Debt interest rate	**%**	**7**
Debt term	**Year**	**15**

Table 3. Initial costs

Initial cost	31%	$	234,000,000
User-defined	69%	$	520,000,000
Total initial costs	**100%**	**$**	**754,000,000**

Table 4. Yearly cash Flows

Yearly Cash Flows -Year 1 **Annual Cost and Debt Payments**		
O&M cost (savings)	$	52,560,000
User-defined	$	34,037,532
Debt payments- 15 years	$	57,949,603
Total annual costs	**$**	**144,547,135**

Table 5. Annual savings revenue

Annual savings and revenue		
User-defined	$	4,500,000
Electricity export revenue	$	10,065.24 million
GHG reduction revenue	$	0
Other revenue (cost)	$	0
CE production revenue	$	0
Total annual savings and revenue	**$**	**10,065.27 million**
Net yearly cash flow-year 1	**$**	**9,925.192 million**

Annual savings cumulative

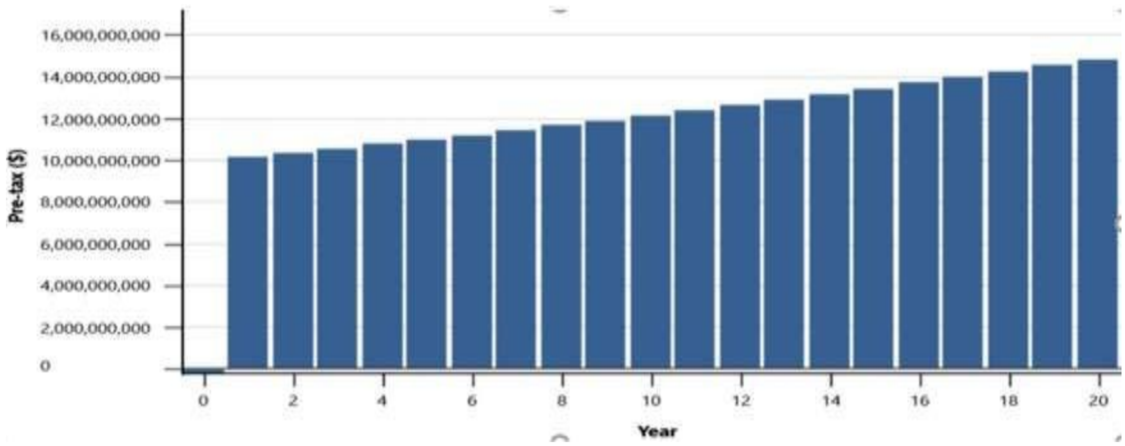

Figure 5. The Annual savings cumulative

Cash flow- Cumulative

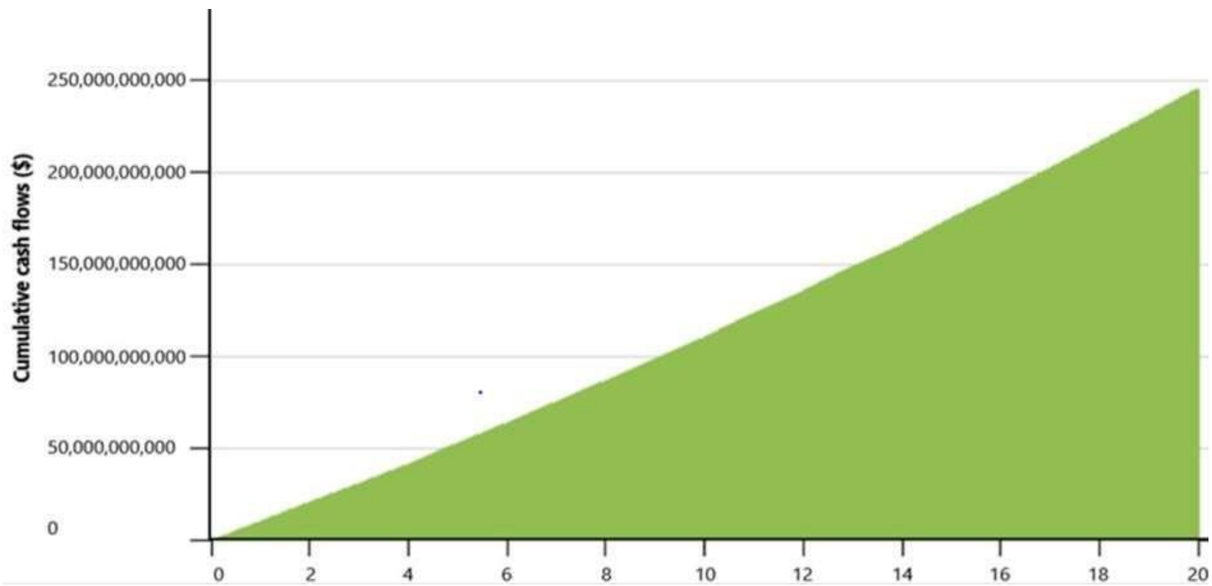

Figure 6. The cash cumulative

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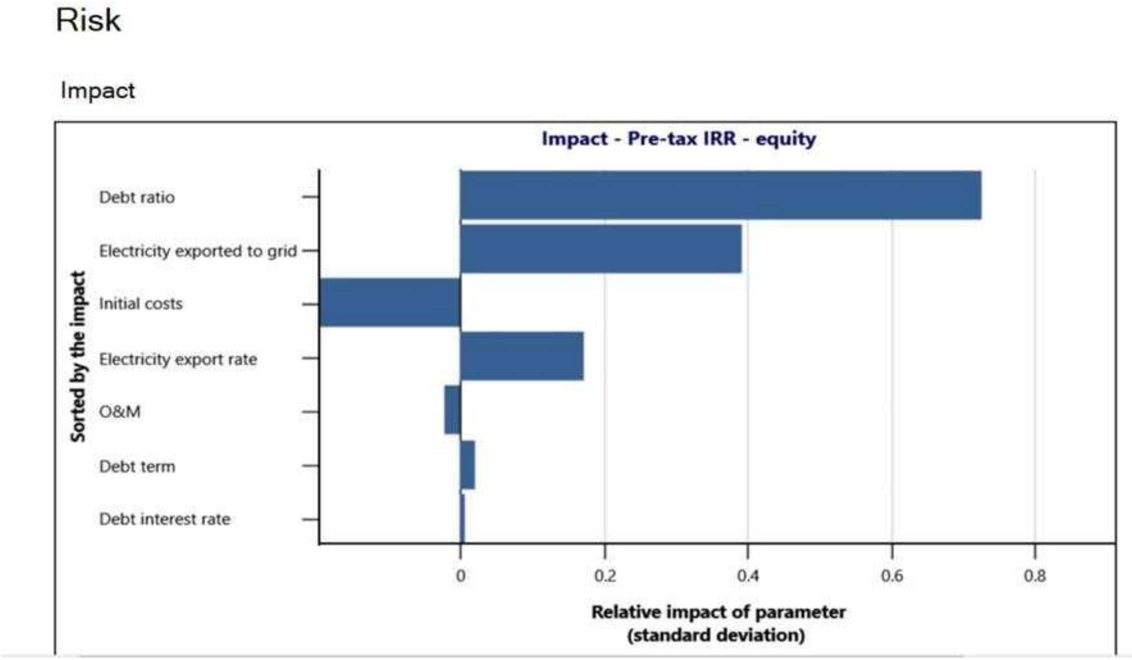

Figure 7. The risk impact of the equity payback

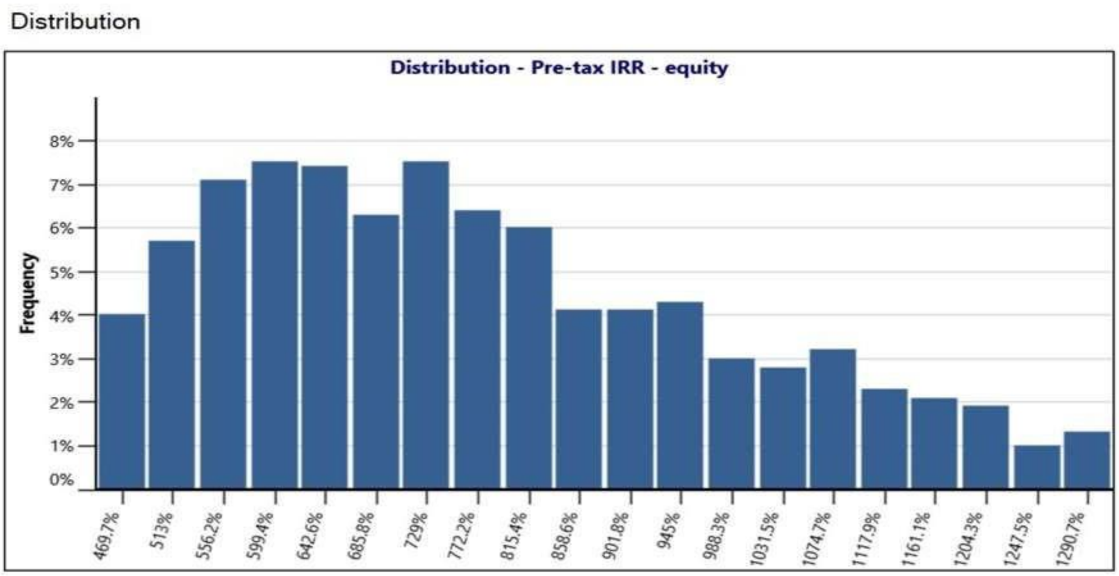

Figure 8. The distribution equity payback graph

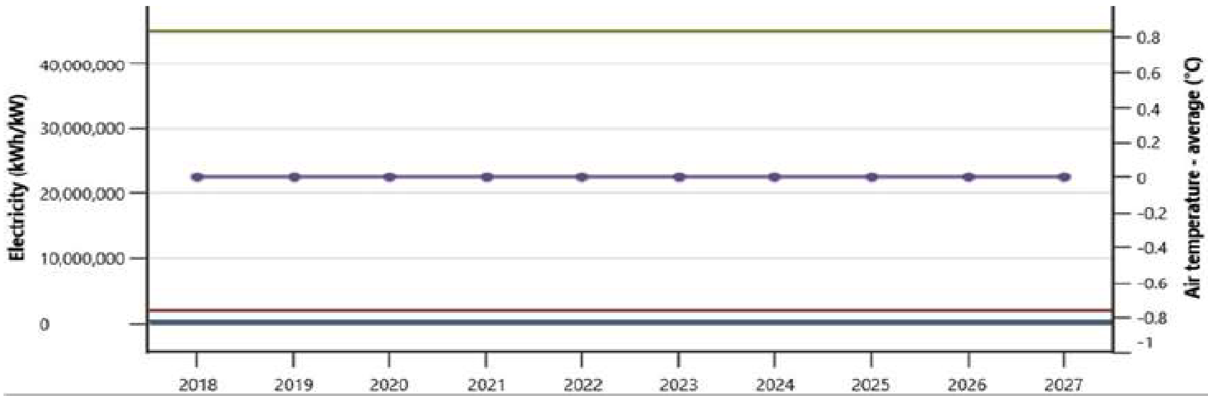

Figure 9. The average utility

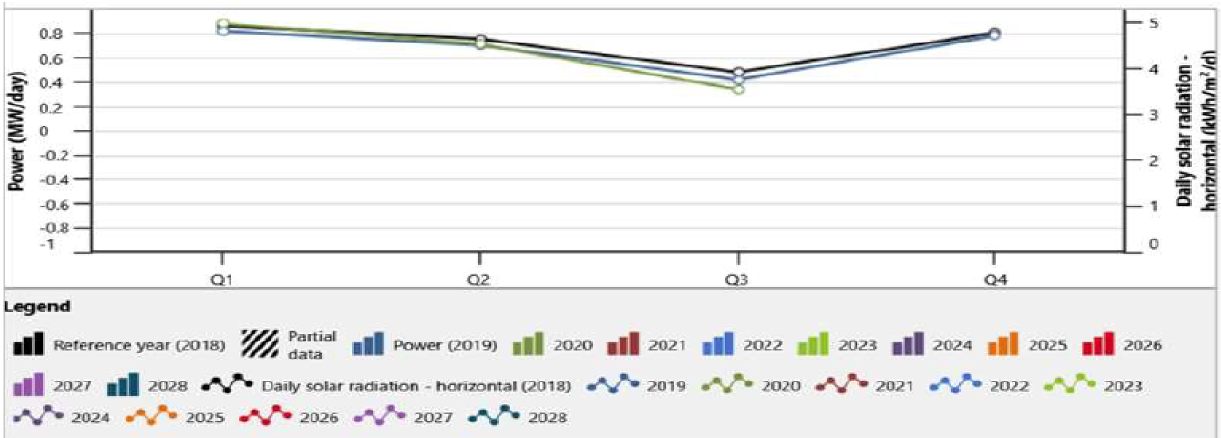

Figure 10. The quarterly power utility

Table 6. Target Proposed Case Summary

Target Proposed Case Summary		Units
Electricity exported to Grid	**13140**	**MWh**
Electricity export revenue	**10,065,240,000**	**$**
GHG emission reduction	**5,593,093**	**tCO2**

3.1. System description of the Project

The facility site is at the Cape Coast, Central Region of Ghana, approximately 100 km from Egyaa Township, in which Municipal Assembly is located. There is a 5.5 km2 level hill, steep, and series of falls dropping about 110 m. The concrete storage is about approximately 2m high, and 800 m long would need to be constructed. The reconnaissance survey determined that a 400 m2 powerhouse.

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The powerhouse consists of a reinforced concrete foundation supporting the building containing a single Francis turbine of a generator with a rate output of 3000MW at 50 power factors built at the base of the falls. A 600 m long tunnel and a 50 m long, 2 m diameter steel penstock for the powerhouse's conveyance would be required. The intake structure level of land in which the tunnel comes up under and the final blast removes the last plug of rock. The powerhouse consists of a reinforced concrete foundation supporting a steel frame building complete with an overhead crane for ma-chine servicing.

The powerhouse contains a Francis turbine/generator unit producing up to 3000000 kW of power as well as ancillary equipment include a governor, control panel, and switchgear. The power generated is fed from the powerhouse to a 0.5 km, 14 kV overhead transmission line. The power would be pass through a substation, where the voltage is increased to 69 kV and connected to the central grid. The proposed facility is in the Cape Coast Central region of Ghana. The Solar thermal plant of 3000MW supply nearly the grid with a 50% power factor. The electricity exported to grid 13140MWh of the 10065 million dollars while the Green House Gas GHG emission reduction was 5.5 million tCO2, and the total initial cost for the facility was 754 Million Dollars, at a rate of 59% for 20-year project life. The design was initially conceived as an innovative trial conception for electricity supplies under 3000 MW within that community.

Table 7. Gross annual GHG emission reduction

GHG emission		
Base case	6,214,547.7	tCO2
Proposed case	621,454.8	tCO2
Gross annual GHG emission reduction	**5,593.093**	**tCO2**

4. Conclusion and Recommendations

This paper seeks analyze the technical and economic performance of the solar thermal plant system based on solar energy potentials for the domestic consumer in Ghana and to assess all the financial viability for the facility. The study explored RETScreen tools to optimization to meet Ghana's electricity demand based on available energy resources and technologies. were analysis in the study revealed that Ghana stands the great potential to expand its electric power source to Renewable Energy Technologies (RET). This study would ensure an efficient and sustainable supply of electricity in Ghana to meet energy requirements soon and eradicate power outages in the country gradually.

- *The findings revealed that if Ghana could be afforded to develop the Solar Thermal Plant generation system with the high deployment of RET, additional benefits in the form of carbon trading could be achieved; Ghana electricity challenges can be solved.*
- *In most projects, the developer continually refines all the above variables (other than the electricity price). The developer of the Cape Coast project would be optimized all the variables within its level of risk tolerance and still found that the price offered by the utility would be minimal. The Project may become financially inviable in the future if the utility's cost of generation is rising, such that the electricity price escalation rate exceeds the inflation rate. In most situations, however, the utility's price needs to be adjusted at the outset, as it has been in other areas.*

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

E. N. Kumi, "Challenges and Opportunities CGD Policy Paper 109 September 2017," no. September, p. 30, 2017.

B. Belgasim, Y. Aldali, M. J. R. Abdunnabi, G. Hashem, and K. Hossin, "The potential of concentrating solar power (CSP) for electricity generation in Libya," Renew. Sustain. Energy Rev., vol. 90, no. January 2017, pp. 1–15, 2018, doi: 10.1016/j.rser.2018.03.045.

A. Aragon-Zavala, "System Requirements," Indoor Wirel. Commun., pp. 45–76, 2017, doi: 10.1002/9781119004547.ch3.

F. Opoku, M. Of, S. In, and M. Engineering, "ELECTRIC-POWER GENERATION IN NORTHERN," no. July, 2010.

F. A. Asante, S. Bawakyillenuo, N. Bird, N. C. Trujillo, C. A. Tagoe, and N. Ashiabi, "Climate change finance in Ghana," no. June, pp. 1–105, 2015.

A. Khellaf, Overview of Economic Viability and Social Impact of Renewable Energy Deployment in Africa, vol. 2018, no. Reris. Springer International Publishing, 2018.

C. Mensah and M. M. Mensah, "Climate Change and the Viability of Renewable Energy in Ghana," Innov. Energy Res., vol. 07, no. 02, 2018, doi: 10.4172/2576-1463.1000196.

K. A. Emmanuel, "Technical & Economic Viability Analysis of Renewable Energy Technologies in Ghana.," Renew. Energy, vol. 12, no. 23, pp. 45–220, 2005.

E. B. Agyekum, V. I. Velkin, and I. Hossain, "Comparative evaluation of renewable energy scenario in Ghana," IOP Conf. Ser. Mater. Sci. Eng., vol. 643, no. 1, 2019, doi: 10.1088/1757-899X/643/1/012157.

"RETScreen Expert - Professional mode - Order form," p. 869.