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Techno-Economic Viability of Solar Thermal Power Generation in Southwest Nigeria

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Abstract

Being the capital of global energy poverty with over 0.65billion people representing more than 50% of its population lacking access to electricity, Sub-Saharan Africa, led by Nigeria with over 90million people without modern energy, of which over 70% depend on biomass, the need for a sustainable energy solution is an urgent imperative for the whole region. Despite having the highest solar energy potential globally, solar mini-grids are yet to achieve documented commercial success, which has hampered investment over the years, culminating in a high unemployment rate, insecurity, and socioeconomic underdevelopment. The viability of solar thermal energy (STP) systems for sustainable commercial Solar Thermal Power (STP) generation in Southwest Nigeria was investigated and analysed by acquiring a 21–year mean generic solar insolation and ancillary data for 23 evenly distributed cities across the geopolitical zones, with at least 3 selected from each of the 6 states. The technical and commercial feasibility was evaluated and analysed using Techno–Economic Renewable Energy Viability Index (TEREVI), Techno–Economic Levelized Cost of Electricity (TELCOE), conventional Levelized Cost of Electricity (LCOE), MATLAB Simulink, and HOMER Software simulated Cost of Electricity (COE) based on a 100kW plant mini-grid model in hybrid configuration interoperable with other grids, which yielded values of 0.836, \$0.023/kWh, \$0.022/kWh, \$0.0.0309010/kWh and \$0.018/kWh, respectively. Southwest Nigeria has a high solar heating intensity with a year-round average above the minimum threshold for STE power generation, which, coupled with the results of its techno–economic metrics, shows high market competitiveness for viable commercial operation, whether in short, medium, or long-term applications for mini-grid generation or steam integration with conventional power plants to optimize energy supply, cost, and greenhouse gas emission.

Keywords: solar thermal energy, solar thermal power, heliostat, high temperature thermal energy storage (HTES), TEREVI, TELCOE, LCOE, solar insolation

1.0. Introduction

Despite the huge solar energy potential of Nigeria such that 1% of the country's landmass is worth about 600,000MW of solar electricity potential, poor and inadequate and epileptic power supply problem and associated consequences continues to linger since the past 5 decades thus making the country home to 85million persons unconnected to grid or any form of clean energy solution with the about 60% connected population lacking constant power supply on average of about 60% of the time or more(Sambo, 2011; Nasir, 2021).

Though frantic efforts have continued to be made by the Federal Government in the last 23years with over \$16billion invested, national power generation has appeared to be static at around 3,000MW – 4,000MW average not mentioning frequent grid collapses while only about 80% of urban and 30% or rural households are connected to the national grid(Asadu, 2020; Trading Economics, 2023).

However, the overly poor efficiency of the national grid transmission and distribution systems coupled with obsolescence, energy theft and vandalization amounting to about 30% of energy being lost along the lines means the current centralized grid system of about 20,000Km length and 8,000MW capacity is no longer suitable for fit any practical solution to power supply problem hence the calls by experts for its unbundling, introduction of embedded power supply, and alternative energy driven mini – grids especially for rural and unserved communities(Okwori 2011, NERC, 2023)

Figure 1.1: Hybrid power mini-grid systems concatenated clusters (Okwori et al, 2025).

As a tropical country, Nigeria is located at Latitude 9.081 and longitude 8.675 along the equator and bounded in the north and south by the Sahara Desert and Atlantic Ocean respectively which makes her an ideal solar energy endowed nation with intensities varying from moderately high at the mangrove tropical rainforest southern zones to extremely high at the Sudan and Sahelian savannah northern axis thus suggesting strong opportunities for both solar photovoltaic (SPV) and solar thermal energy (STE) farms respectively(Falola and Ajayi, 2025).

STE farm for Solar Thermal Power (STP) is veritable means of relatively high efficiency solar energy conversion system due to the technology's dispatchability, cheaper storage per unit energy, higher power to space ratio, and flexibility added to the fact that it works best with higher solar insolation compared to SPV modules whose power conversion efficiencies tend to start dropping at higher insolations above 32◦C. Though Southwest Nigeria is blessed with excellent vertical, horizontal, and directional solar irradiation fit for flat and convex photovoltaic and heliostat modules, for large baseload solar power generation, STE is a strategic solution to addressing power problems especially for large mini – grids and mains interoperable grid systems for baseload power supply due to its dispatchability and high storage capacity among other things (Merchan et al, 2021).

While SPV projects are common in most parts of Nigeria, there is yet to be one major STP plant in Nigeria despite the vast endowment and exigencies. Exploring and exploiting the STE potentials in Southwest Nigeria is key to addressing the region's high domestic, industrial, and agricultural power needs as well as serving as a veritable model for the rest of the country. This study is inspired by the need to address the massive energy poverty and poor electricity supply induced de-industrialization as well as other problems like agricultural losses, unemployment, insecurity, and rural infrastructural shortage among other issues by the exploration and utilization of locally available clean and affordable renewable energy resources especially solar to power interoperable networks of distributed mini – grids (Towoju, 2025).

This study aims to change the national and regional power development strategies from the current top-down approach focused on main grid systems to bottom-up systems based on autonomous renewable energy mini-grids independently but interconnected and interoperably serving local loads while also feeding excess to other connected mini-grids (MGs) in concatenated hybrid configurations as shown in Figure 1.1. By this, solar-thermal, like other locally available renewable energies, will feed mini-grids of less than 1MW capacity or typically ≤100kW. The choice of small sizes is based on the experience of the practical experience of the authors which empirical shows that the capacity of solar power plants generally needs to be limited in sizes to reduce optimize the lifecycle cost, technical complexity, return on investment, maintenance, logistics, learning curve, and administrative efficiencies especially considering rural community ownership management for greater sustainability. This means that for solar mini-grid, there is a size that is too big and usually best kept well within units of 1MW. Hence, it's best to have multiple small mini-grid capacities serving different loads than a single large capacity serving all loads (Okwori et al, 2025).

2.0. Literature Review

Ogunmodimu and Okoroigwe (2019) studied the lack of concentrated solar panel thermal power investment in Nigeria and concluded that despite having higher potentials than ost existing successful project sites, the presence of fuel subsidy, high capital expenditure, leadership inefficiencies, and technological cost are the main problems. However, the study did not address techno-economic interactions and how they affect the systems. This also did not build a case or energy model to guide judgment.

Similarly, Adeyanju and Wanosher (2011) examined the prospects of solar thermal energy in Nigeria. They concluded that the potential is high and even better than some locations with concentrated solar panel projects. However, the economic aspect as well as several administrative factors make the system not commercially competitive. Although this study is not based on a case, whether by design, simulation, or an existing project, it nonetheless highlights some of the critical subterranean factors that hinder the development of renewable energy mini-grids, generally in Nigeria and Sub-Saharan Africa at large.

Agyekum and Velkin (2020) investigated the techno-economic performance and optimisation of a solar thermal system based on two solar technologies. In the study, they used the System Advisor Model (SAM) desktop software to simulate a solar thermal tower at Navrongo and a solar thermal parabolic trough at Tamale, all in Southwestern Ghana, with Solar Multiple of 1.4 and 1.5. Their study concluded that solar thermal generation is feasible in Ghana, but with different financing conditions from the conventional funding practices, as well as extra efforts from both decision makers and policy makers, among other things, to be addressed. This further corroborates the uncertainties and knowledge gaps responsible for the failure of most renewable energy projects, especially solar mini-grids.

Ramde et al (2020) based on their study of a small-scale solar CSP plant in Northern Ghana, concluded that the major drawback of solar–thermal power generation is the excessive energy cost of the solar tracking system and its suboptimal efficiencies, which is also technically challenging to optimize.

Labordena et al (2017) based on studies carried out on solar-thermal plants in South Africa, observed that the numerous risks of various kinds, including political, social, administrative, financial, environmental, and economic, are the main challenging factors. They further noted that while the cost of solar-thermal systems is anticipated to equal that of coal in a few years, most Sub-Saharan Africans will continue to experience difficulties in achieving cost cost-effective solar-thermal power system.

Abdullahi et al (2022) investigated the barriers to solar energy implementation in Nigeria and observed that a combination of political, social, economic, and leadership issues is responsible, even though the country is generally rich in solar energy potential. This further goes to explain why conventional energy modelling tools and planning systems have not yielded significant success in the development of solar mini-grids in Sub-Saharan Africa. Thus, a broad and less complicated approach that captures all critical factors that address local issues is very important for future developments.

3.0. Methodology

The research on solar thermal energy is based on a techno-economic assessment of the energy generation technologies. Hence, this research begins with an overview of solar energy resources based on empirical perception, climate conditions, and project precedents of solar thermal power generation within or in proximal locations, before proceeding to real-time data acquisition.

Mean daily 21-year solar energy data for 23 selected stations across Southwest, Nigeria, were obtained from the EarthData of the Langley Research Center (LaRC) of the National Aeronautics and Space Administration. (NASA). Similar data were also acquired from the National Renewable Energy Laboratory (NREL) and the Nigerian Meteorological Agency (NIMET) records, which were used as a comparison with the LaRC as primary data to ensure accuracy and data integrity.

A 100kW hypothetical solar thermal power based on parabolic trough heliostat concentrated solar power (CSP) technology was designed, incorporating high heat capacity specialized salt-based high temperature energy storage system (HTES) to provide night steam to the steam turbine generator (STG) after sunset with 8hours worth of energy storage capacity using a solar multiple of 1.75 and generator power factor of 0.8, as shown in the plant schematic represented by Figure 3.4 while Figure 3.2 and 3.3 show the hybrid power schematic and the solar-thermal powertrain respectively. The HTESS is designed with the capacity to be able to continue generating power for 8 hours past sunset, but could be optimally dispatched to keep producing power until sunrise; hence, nocturnal load is expected to be much less than day load for residential communities, offices, and villages.

The solar-thermal mini-grid commercial viability assessment research project is based on the flow chart in Figure 3.1. The system is designed to be evaluated based on many models that may be available for multi-layered commerciality proof. Hence, the TEREVI, TELCOE, HOMER, and the MATLAB Simulink were applied while the systems is equally open for other techno-economic metrics, tools, and models for further testing if at all necessary.

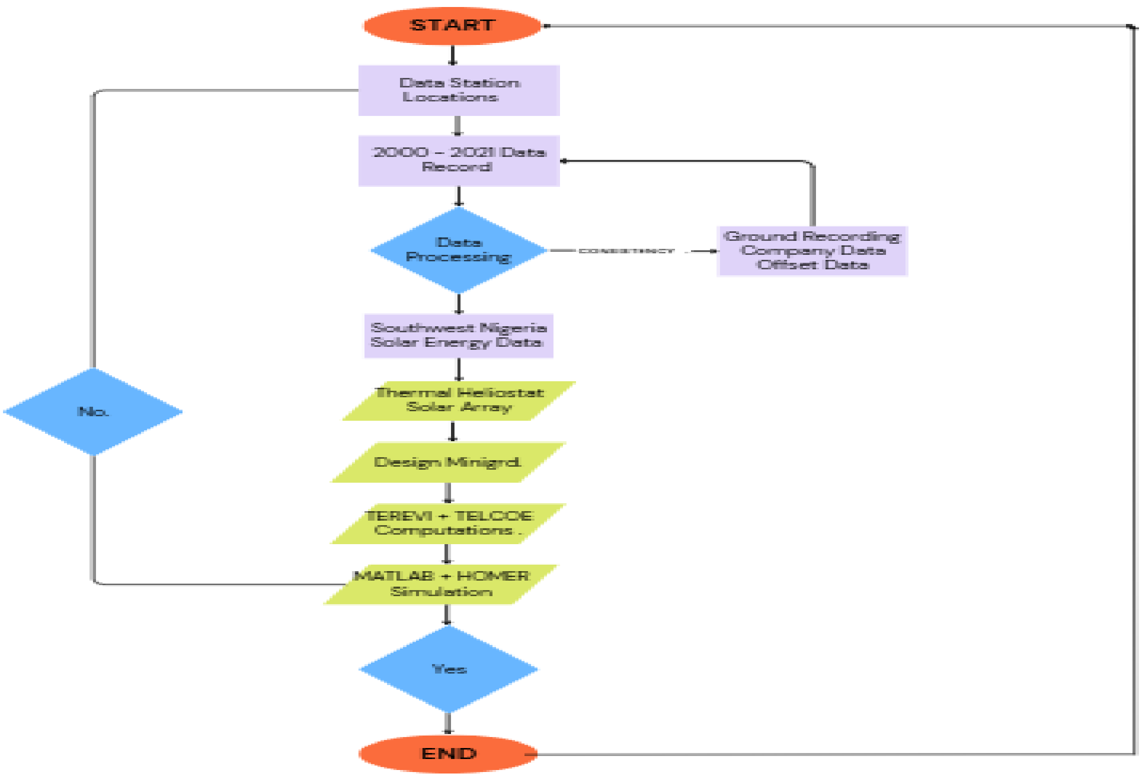

Fig. 3.1: Flow chat of the techno-economic viability study of solar thermal energy

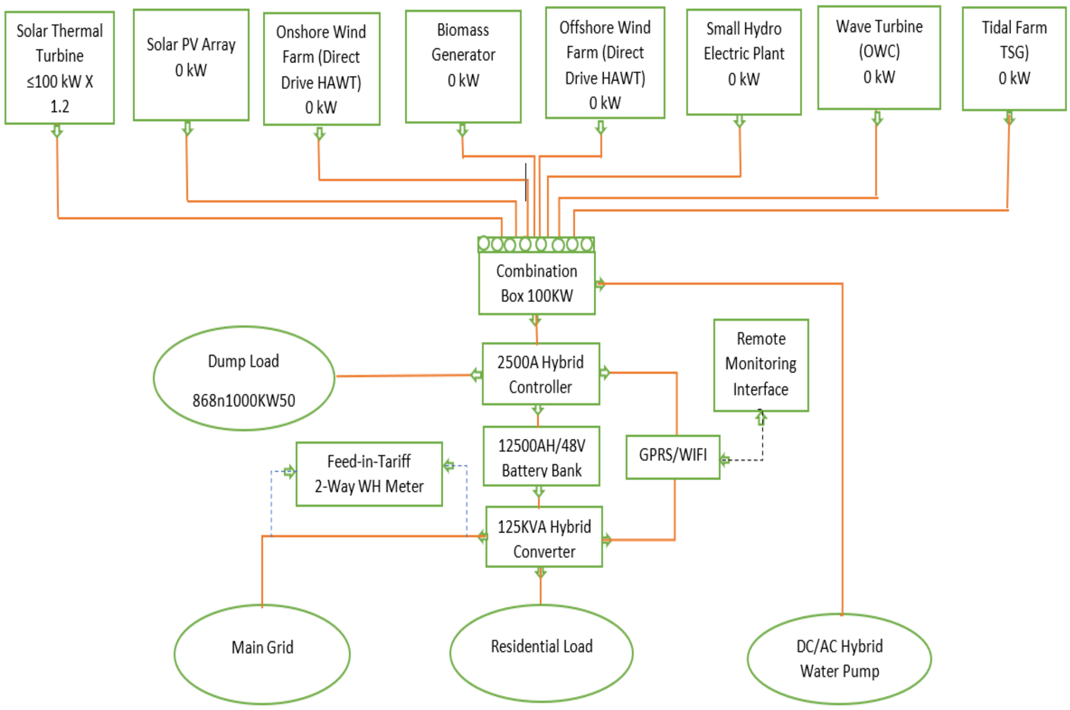

Fig. e 3.2: solar thermal power in hybrid min-grid design

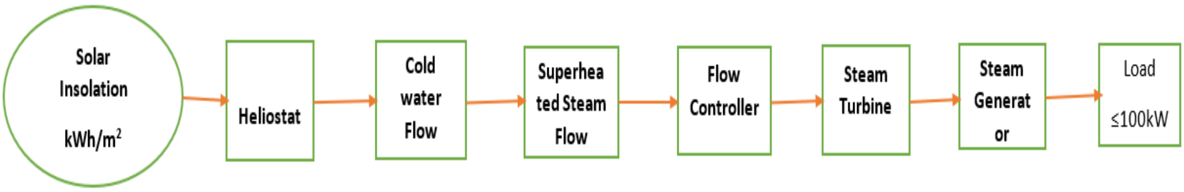

Fig. 3.3: solar thermal powertrain

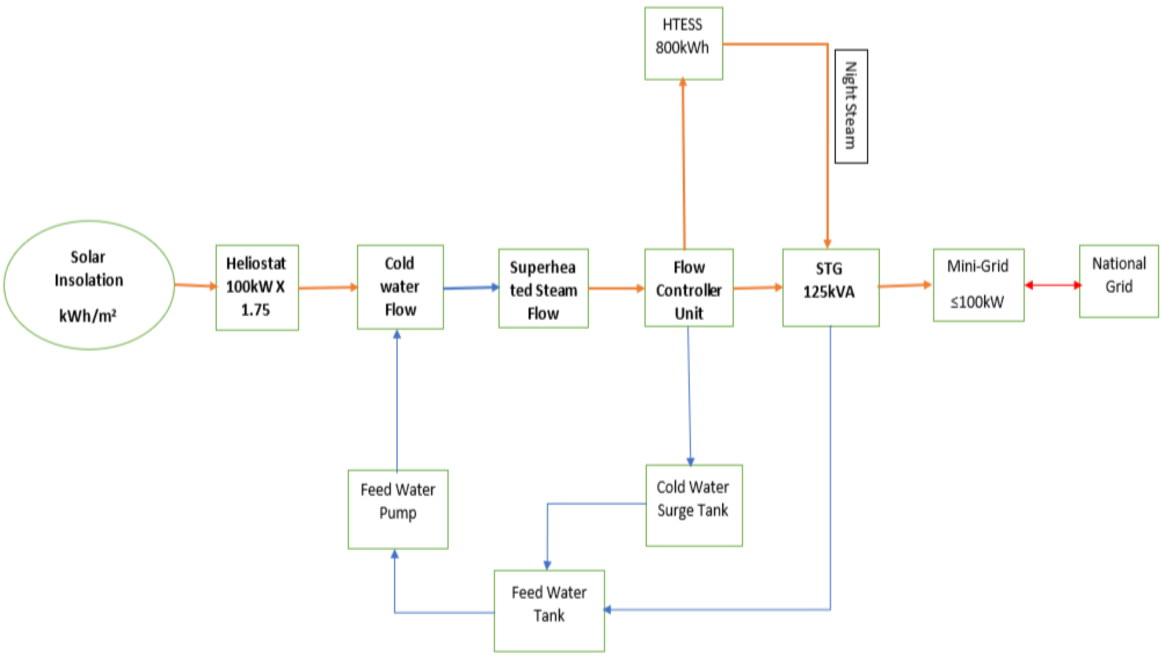

Fig. 3.4: Process flow diagram of the 100kW solar-thermal plant

3.1. Solar Thermal Power Technology and Theory

Solar thermal energy (STE) is electricity generated from the concentration of non-deviated direct normal radiation (DNI) also called beam radiation on concave concentrating mirrors or plates called heliostats and most applicable at geographical locations less than 40◦ of latitude north or south of the equator and fairly rarified with minimal dust, humidity, atmospheric fumes and particulates (ESTELA, 2022).

The TuNur solar thermal project in the southern fringe of Tunisia on the Sahara Desert, which also borders some Nigerian states, is a 2-phase modular design of 250W and 2,000MW respectively to power 2.5million European homes via a 1000Km HVDC interconnector cables at transmission loss of just about 3% running from underground past the Mediterranean Sea traversing Malta to Italy from where it supplies the central European grid system (Kelvin, 2015).

The project is designed with a molten salt storage system that is capable of being heated by the heliostats and maintaining its temperature at about 550◦C (Kelvin, 2015) to release for generating steam to power from sunset hours. The project is driven by a group of companies including Nur Energie (a United Kingdom independent power plant developer), Low Carbon (a United Kingdom green energy investor), Glory Clean Energy (a Franco – Tunisian green energy industrial project developer), Zammit Group (a Tunisian conglomerate), and Desertek (a German global non – profit on alternative energy and sustainable future).

The TuNur LCOE is at £1.2/KWh in the first phase of 250MW capacity and £0.03/KWh in the second phase of 2000MW, compared to £4.9/KWh for nuclear power and £2.6/KWh for offshore wind electricity (Kelvin, 2015). The project construction phase has a socioeconomic impact of 20,000 direct and indirect jobs, aside from local contractor supplies, and an operational phase of 1000 jobs, aside from enhancing Tunisia's energy security and inspiring several more projects such as the proposed MASEN's 2000MW solar thermal power export to Europe (Kelvin, 2015).

STE module systems are designed, applied, and classified based on heat requirements as Low – Low-Low-Temperature, Medium–Temperature, and High, and may be either concentrated solar power (CSP), for power generation or concentrated solar thermal (CST), for industrial or commercial heating solutions and ancillary services. For power generation, only high–temperature heliostats are used, while low and medium-temperature heliostats are used.

Solar thermal power systems have efficiencies well up to 70% compared to solar PV, which ranges from about 15% to 25% and are most suitable for commercial or high-capacity application stations, aside from power generation, providing heat for other needs. Unlike PV panels, STE panels are not effective in cold weather except with the use of thermodynamic panels and do save more than 3 times the space of Solar PV (McCloy, 2019). An STE in suitable locations like South–West Nigeria will generate at least 100,000MWh/annum or equivalent of 50MW coal or gas-fired CCGT/OCGT plant, save at least 200Kg of GHG/year, and yield equivalent energy of 5million barrels of crude in its minimum 30-year lifecycle, and added to the fact that most components of STE are recyclable (ESTELA,2022).

Prospective STE sites must have at least 3.7KWH/m2/day or 1,200KWH to 2000KWh/annum worth of direct sunlight per square meter while highly viable sites have over 2800KWh worth of DNI power per square meter though more recent high efficiency heliostats, boilers, and heat transfer technologies now enables STP plants in locations as low as 1,000KW/m2/year or a little less depending mostly on economic considerations (Franco, 2020; ESTELA, 2022; EnergyPedia,2018).

STE collectors are typically composed of specially reinforced glass pipes (usually embedded in insulated containers to minimize heat loss) with a special material coating which enables it to optimally capture and convert DNI to heat. The glass pipes are usually embedded in an insulated container, which helps prevent loss of heat energy (McCloy, 2019).Concentrating mirrors or plates may be designed based on either Point Focusing System (PFS), which can concentrate solar radiation up to about 1000time with temperatures up to 1000◦C or Line Focusing System (LFS), which can concentrate solar radiation up to 100times with temperature up to about 600◦C (ESTELA, 2022).

There are four different commercial–scale CSP technologies which are made up of 2 PFS types (central receiver and parabolic dishes) and 2 LFS types (parabolic trough and linear Fresnel system). Micro CSP are used for power mini – grids with capacity of less than 100MW. CSP plants are cooled via any of 3 cooling methods: dry cooling, which is based on air; wet cooling or evaporative cooling, which is based on water; and hybrid cooling, which is based on optimized use of both wet and dry cooling techniques in order to synergize for lower cost, efficient heat exchange, safety, and timeliness, etc.

All the STE Energy Storage System (ESS) technologies are generally referred to as Hight Temperature Thermal Energy Storage (HTTES) as opposed to Battery Energy Storage System (BESS) for solar PV system. Though advantageous, air cooling can up CAPEX to 10% higher than water cooling STE can be stored for night time such as the 50MW Andasol CSP plant in Spain with 8 hours of storage using liquid or solid media such as molten salt, ceramic concentrate, phase-changing salt mixtures (ESTELA) or steam accumulator (Biello, 2008). Steam Accumulator is based on the storage of excess steam at high pressure in a heat tank by which the steam condenses but regasifies once released to the turbine for use after sunset. The technical limitation for steam accumulators has to do with safety and the short storage holding capacity which can actually be increase with larger tanks.

Molten salt energy storage is current practices most commonly based on the use of high-grade calcium nitrates and other premium salt derivatives that could maintain storage temperature well over 500◦C in salt tanks for hours and released to heat the water after sunset to generate steam into electricity. Phase Change Materials energy storage technology are based on use of at least 3 different salt capsules in the salt tank taking advantage of the fact that the salts of choice in capsule undergo expansion up to 50% during heating thus increasing its energy density or reducing salt volume about 50% compared to molten salt storage which could be further enhanced based on technoeconomic considerations like salt cost, heat of fusion and availability (Terrafore et al, 2014).

Novel HTTES such as the Storasol Fast Charging - Fast Discharging Solid Bed Storage Material Arrangement based on use of small gravels plus sand mixture and circulating ambient air to store and transfer heat at temperatures well over 600◦C respectively usually designed and built in modular units (Battisti, 2018).With HTTES cost generally at \$16.2/KWh to \$75.6/KWh, molten salt energy storage tanks are 1/30th to 1/90th the cost of lithium-ion BESS technologies whose costs vary between \$899.64/KWh and \$1,512/KWh with respect to temperature differences, capacity and operational efficiencies among other pivotal variables (BVES, 2017; Battisti, 2018).

The molten salt HTTES system efficiency ranges from 90% up to 99% thus a daily heat loss of between 1% and 5% with typically 10,000 cycle lifespan given high average operating temperature ranges between 120◦C and 600◦C coupled with massive unit storage capacities from 75KWH/m3 to 200KWH/m3 or 40KWh to 110KWh per metric ton(BVES, 2017). STE is dispatchable and storable and thus has a high capacity factor and can be switched on or capacity varied to follow the demand curve which makes it a good match for commercial scale power generation, has a lifespan of at least 30 years, has minimal performance loss and most of its components are recyclable (ESTELA, 2022). During operations, the pipes convey heat transfer fluids called thermal fluids which could be water, ethylene glycol or a blend of both running in closed loop network with a configuration of 2 tanks: the hot water tank and the combination tank (with a mixture of cold and hot water).

Other STP components include a coiled heat exchanger (temperature management), a pump (liquid transportation along the pipework to CSP), a control panel (process control and safety management), an insulated pipe, and a heat flow generation meter (for heat sales or valuation). Solar Heat Engine is another STE technology, very similar but a slight variant to the CSP that has a parabolic dish concentrator similar in structure to a satellite dish and a power conversion unit (PCU) mounted on its focus as the main components. Though very efficient and have the highest solar–power ratio (Sergeant and Lundy, 2003) compared to other solar technologies, due to structural issues and ratios, it is techno-economically difficult and non–viable to build large single units beyond 1KW to 50KW and thus best suited for small capacities of typically 1KWh – 50KWh and good for modular installation (DOE, 2020).

The Solar Thermal Heat Engine system directs the concentrated heat from a parabolic dish reflector to a receiver unit, which gasifies a fluid in a tubular configuration, which is in turn channeled to move the pistons of a reciprocating internal combustion engine, usually of the Sterling Engine design or a steam turbine. The PCU mounted at the parabolic dish's focus is composed of both the receiver and the engine/turbine. For maximum power generation, the solar–heat engine concentrator dish is built with multi–axial tracking ability using a universal joint in order to keep its center constantly facing and following the sun in the direction of the equator from sunrise to sunset. Though very impressive with great promises in the near future, STP–engine technology is at the moment very limited in use owing to technical complexities, the need for many units, and space for commercial-scale power generation, and the cost of operation and maintenance (Desai, 2013).

Based on the First Law of Thermodynamics, the thermal fluid heat absorption rate $\dot{H}_F$ on the STP system is the difference between the incident radiation, the insolation heat flow $\dot{H}_I$ and the sum of total heat loss, that is; radiation heat loss $\dot{H}_R$, convection heat loss due to the high flow rate of liquid and subsequently high Reynold Number in the order of 10^5 alongside pipe design and flow regime H_V and concentrator material's conduction heat loss $\dot{H}_C$;

$$\dot{H}_F = \dot{H}_I - \left[\dot{H}_R + \dot{H}_V + \dot{H}_C\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

The mass flow coefficient, $\boldsymbol{\Omega}$, with respect to the mass flow rate of fluid $\dot{\boldsymbol{F}}$, fluid density $\boldsymbol{\rho}$, pressure P, and temperature T across sections of the pipework (Cookie, 1983) is given by:

$$\Omega = \frac{\dot{F}}{\sqrt{\rho P}} = \frac{\dot{F}\sqrt{T}}{P} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Given the elliptic constant Z, according to Spelling (2011 and Cookie (1983), the backpressure P_B is obtained with respect to the critical back pressure P_{CB}, inlet temperature T_i, and mass flow rate by:

$$P_B = \sqrt{P_{CB}^2 - \dot{M}^2 T_i Z} \qquad \ldots\ldots\ldots\ldots\ldots 3.3$$

$$Z = \frac{P_{i,nominal}^2 - P_{c,nominal}^2}{\Omega_{nominal}^2 P_{i,nominal}^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

For the heat exchanger, maximum temperature transfer is achieved by counter-flow configuration between the two fluids. Hence, given that the minimum specific heat capacity between the 2 fluids exchanging heat is C_{min}, the inlet temperatures of the cold and hot streams are T_{ih} and T_{ic}, respectively, the theoretical heat transfer is given by:

$$\dot{H}_{max} = C_{min}[T_{ih} - T_{ic}] \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

Given the heat transfer efficiency to be η, overall heat transfer coefficient U, surface area of heat exchanger A_s, change in minimum approach temperature ΔT_{min}, the number of transfer units (NTU), and specific heat capacity ratio C_R, we have:

$$\dot{H} = \eta \dot{H}_{max} = \eta C_{min}[T_{ih} - T_{ic}] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

$$\eta = 1 - \frac{\Delta T_{min}}{[T_{ih} - T_{ic}]} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

$$C_R = \frac{C_{min}}{C_{max}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3.8$$

$$NTU = \frac{A_s U}{C_{min}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.9$$

By which the NTU effectiveness relationship is given, thus:

For $C_R = 1, \quad NTU = \frac{\eta}{1-\eta}$

$$C_R<1, \quad NTU = \frac{1}{C_r-1} ln \frac{\eta-1}{\eta C_R-1} \qquad \text{…………………3.10}$$

Given the hydraulic efficiency η_H the feed water pump Power W_{pump} is calculated by the equation:

$$W_{pump} = \frac{1}{\eta_H} \dot{M} \frac{\Delta P}{\rho} \qquad \text{…………………3.11}$$

4.0. Data and Results

The primary data was acquired from NASA-LaRC satellite altimetry, while NREL, NIMET, and isolated data acquired were only used to compare notes and nod on the accuracy of primary data. In addition, NASA-LaRC data are more conservative and larger with more specifics and ancillary information, which makes for more robust analysis and interpretation. Tables 4.1 and 4,2 show the solar insolation and solar energy potentials of Southwest, Nigeria, respectively, while Table 4.3 shows the performance of the solar thermal mini-grid through TEREVI, TECLCOE, HOMER, and MATLAB Simulink evaluation models.

AVERAGE ALLSKY SOLAR INSOLATION (KWH/M2/DAY) FOR STRATEGIC LOCATIONS ACROSS SOUTH-WEST NIGERIA 2000 – 2021													
LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
OBAFEMI OWODE	4.90	4.78	4.95	5.02	4.70	3.97	3.89	4.12	4.18	4.67	5.06	4.96	4.60
ABEOKUTA	4.93	4.83	4.98	5.10	4.94	4.43	3.87	3.58	4.06	4.70	5.05	4.93	4.61
ADO EKITI	5.08	4.88	5.00	5.05	4.99	4.54	4.10	3.83	4.22	4.73	5.18	5.09	4.72
IGBOHO	5.20	5.27	5.47	5.49	5.26	4.76	4.08	3.75	4.32	4.86	5.29	5.22	4.91
OKITIPUPA	4.85	4.72	4.88	4.90	4.72	4.12	3.70	3.80	3.95	4.54	5.04	4.93	4.51
SNAKE ISLAND	4.90	4.78	4.95	5.02	4.70	3.97	3.89	4.12	4.18	4.67	5.06	4.96	4.60
AKOKO	5.08	4.88	5.00	5.05	4.99	4.54	4.10	3.83	4.22	4.73	5.18	5.09	4.72
AKURE	5.08	4.88	5.00	5.05	4.99	4.54	4.10	3.83	4.22	4.73	5.18	5.09	4.72
IBADAN	4.93	4.83	4.98	5.10	4.94	4.43	3.87	3.58	4.06	4.70	5.05	4.93	4.61
IGBO ORA	4.93	4.83	4.98	5.10	4.94	4.43	3.87	3.58	4.06	4.70	5.05	4.93	4.61
IJERO EKITI	5.08	4.88	5.00	5.05	4.99	4.54	4.10	3.83	4.22	4.73	5.18	5.09	4.72
IKIRE	4.92	4.82	4.98	5.01	4.89	4.41	3.80	3.52	4.01	4.58	5.09	4.98	4.59
IKORODU	4.90	4.78	4.95	5.02	4.70	3.97	3.89	4.12	4.18	4.67	5.06	4.96	4.60
ILA ORANGUN	5.22	5.28	5.54	5.55	5.29	4.84	4.31	3.98	4.47	5.01	5.46	5.25	5.02
ILESHA	4.92	4.82	4.98	5.01	4.89	4.41	3.80	3.52	4.01	4.58	5.09	4.98	4.59

ISE EKITI	5.08	4.88	5.00	5.05	4.99	4.54	4.10	3.83	4.22	4.73	5.18	5.09	4.72
ISEYIN	4.93	4.83	4.98	5.10	4.94	4.43	3.87	3.58	4.06	4.70	5.05	4.93	4.61
ONDO TOWN	4.92	4.82	4.98	5.01	4.89	4.41	3.80	3.52	4.01	4.58	5.09	4.98	4.59
OSOGBO	4.92	4.82	4.98	5.01	4.89	4.41	3.80	3.52	4.01	4.58	5.09	4.98	4.59
OWO	5.08	4.88	5.00	5.05	4.99	4.54	4.10	3.83	4.22	4.73	5.18	5.09	4.72
SHAGAMU	4.90	4.78	4.95	5.02	4.70	3.97	3.89	4.12	4.18	4.67	5.06	4.96	4.60
LEKKI	4.90	4.78	4.95	5.02	4.70	3.97	3.89	4.12	4.18	4.67	5.06	4.96	4.60
MEAN	4.99	4.86	5.02	5.08	4.91	4.37	3.95	3.79	4.15	4.69	5.12	5.02	4.66

Table 4.1: Mean All-Sky Solar Insolation for Southwest Nigeria.

LOCATION	MEAN INSOLATION(KWH/M2/DAY)	KWH/M2/YR	MEAN SOLAR THERMAL THRESHOLD VARIANCE (KWH/M2/YR	Solar Energy Class
OBAFEMI OWODE	4.6	1679	679	Very High
ABEOKUTA	4.61	1682.65	682.65	Very High
ADO EKITI	4.72	1722.8	722.8	Very High
IGBOHO	4.91	1792.15	792.15	Very High
OKITIPUPA	4.51	1646.15	646.15	Very High
SNAKE ISLAND	4.6	1679	679	Very High
AKOKO	4.72	1722.8	722.8	Very High
AKURE	4.72	1722.8	722.8	Very High
IBADAN	4.61	1682.65	682.65	Very High
IGBO ORA	4.61	1682.65	682.65	Very High
IJERO EKITI	4.72	1722.8	722.8	Very High
IKIRE	4.59	1675.35	675.35	Very High
IKORODU	4.6	1679	679	Very High
ILA ORANGUN	5.02	1832.3	832.3	Very High
ILESHA	4.59	1675.35	675.35	Very High
ISE EKITI	4.72	1722.8	722.8	Very High
ISEYIN	4.61	1682.65	682.65	Very High
ONDO TOWN	4.59	1675.35	675.35	Very High
OSOGBO	4.59	1675.35	675.35	Very High

OWO	4.72	1722.8	722.8	Very High
SHAGAMU	4.6	1679	679	Very High
LEKKI	4.6	1679	679	Very High
MEAN	4.66	1700.9	700.9	Very High

Table 4.2: Mean All Sky insolation, threshold variation, and energy class across selected cities in Southwest Nigeria.

Viability Metric	Score	Remark
TEREVI	0.835528397	Excellent
TELCOE	0.022847	Good
LCOE	0.021518265	Good
HOMER	0.018107	Very Good
MATLAB Simulink	0.0.0309010	Fair

Table 4.3: Southwest Nigeria STP technical and economic feasibility test results for

5.0. Discussion of Results

Solar energy is a potential for commercial power generation and is conventionally subdivided into 4 main classes reflecting their techno–economic values. <2.5KWH/m2/day = Low; 2.5KWH/m2/day – 3.0KWH/m2/day = Good; 3.0KWH/m2/day – 3.5KWH/m2/day = High; 3.5KWH/m2/day – 4.0KWH/m2/day; >4.0KWH/m2/day = Very High (EnergyPedia, 2018).

Southwest Nigeria is a high-power potential area for solar energy conversion systems with an ALL Sky mean ranging from 4.59KWH/m2/day to 5.02KWH/m2/day, being more than 4KWH/m2/day, and a mean that is 1.7 times the conservative threshold of 1000KWH/m2/yr All Sky Value.

At 0.835528397, the TEREVI for Southwest Nigeria is excellent with good, promising market competitiveness and techno–economic viability scores of $0.022847/KWH, TELCOE$0.021518265/KWH LCOE, and a HOMER Software-generated COE of 0.018107 with very high likelihood of getting better in the medium term, given that all figures presented are very conservative.

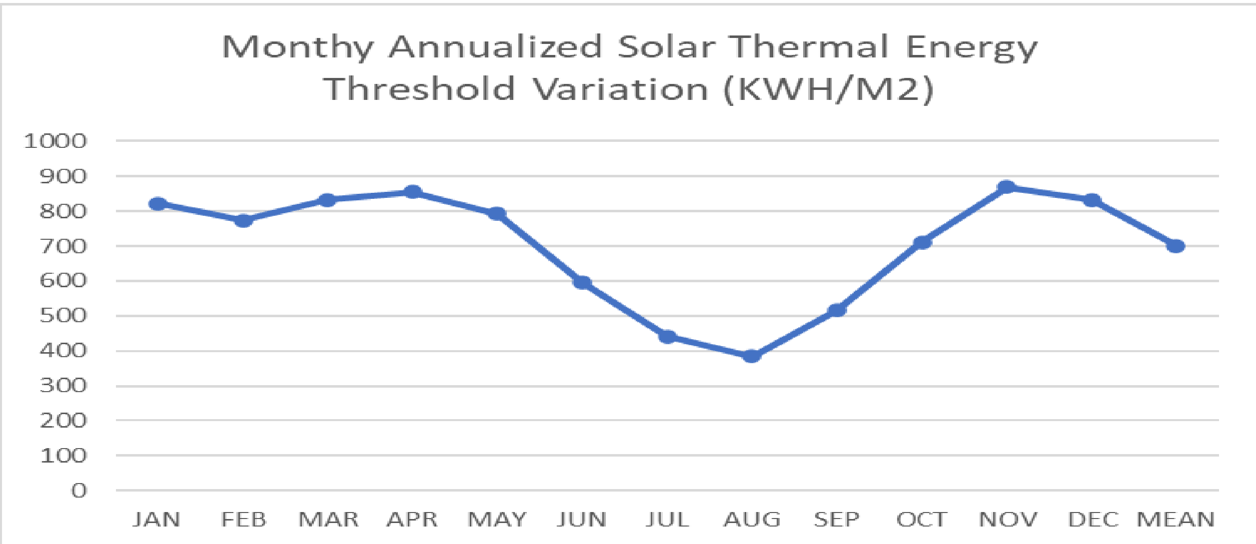

Fig. 5.1: annual unit solar-thermal energy flux in Southwest Nigeria

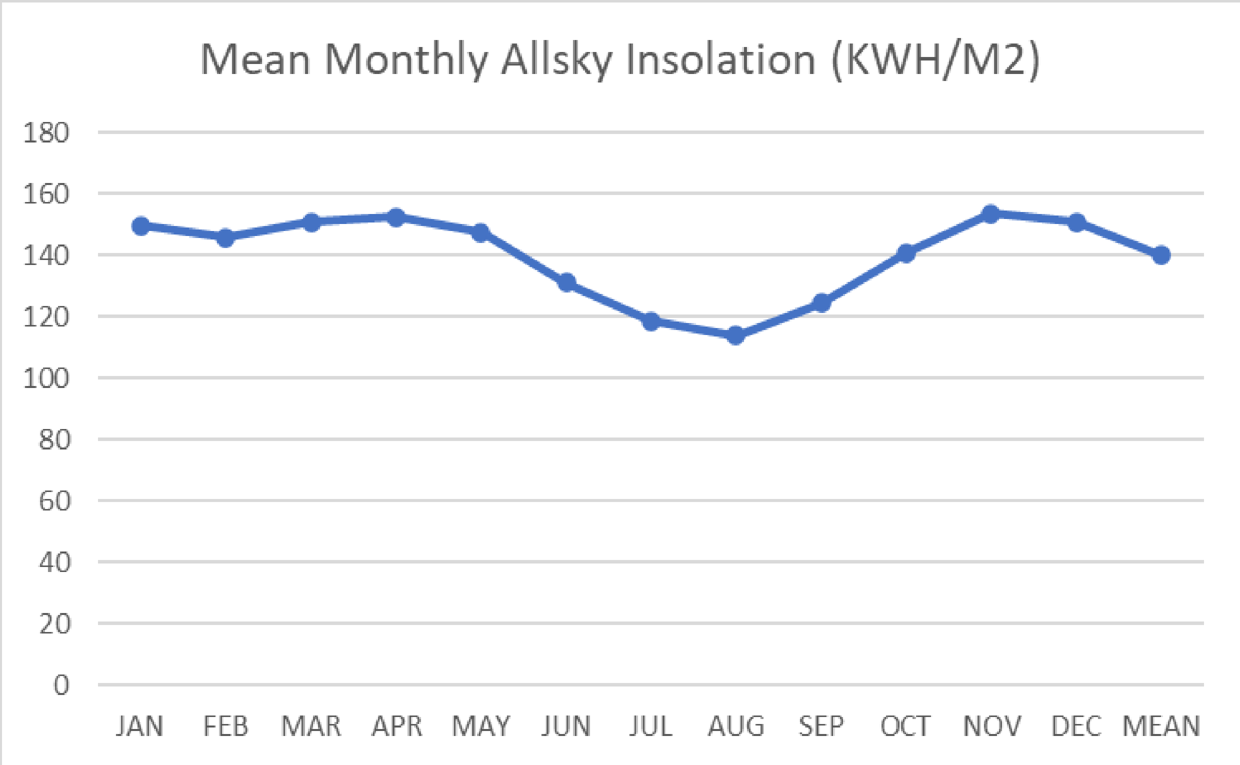

Fig. 5.2: mean monthly insolation in Southwest, Nigeria

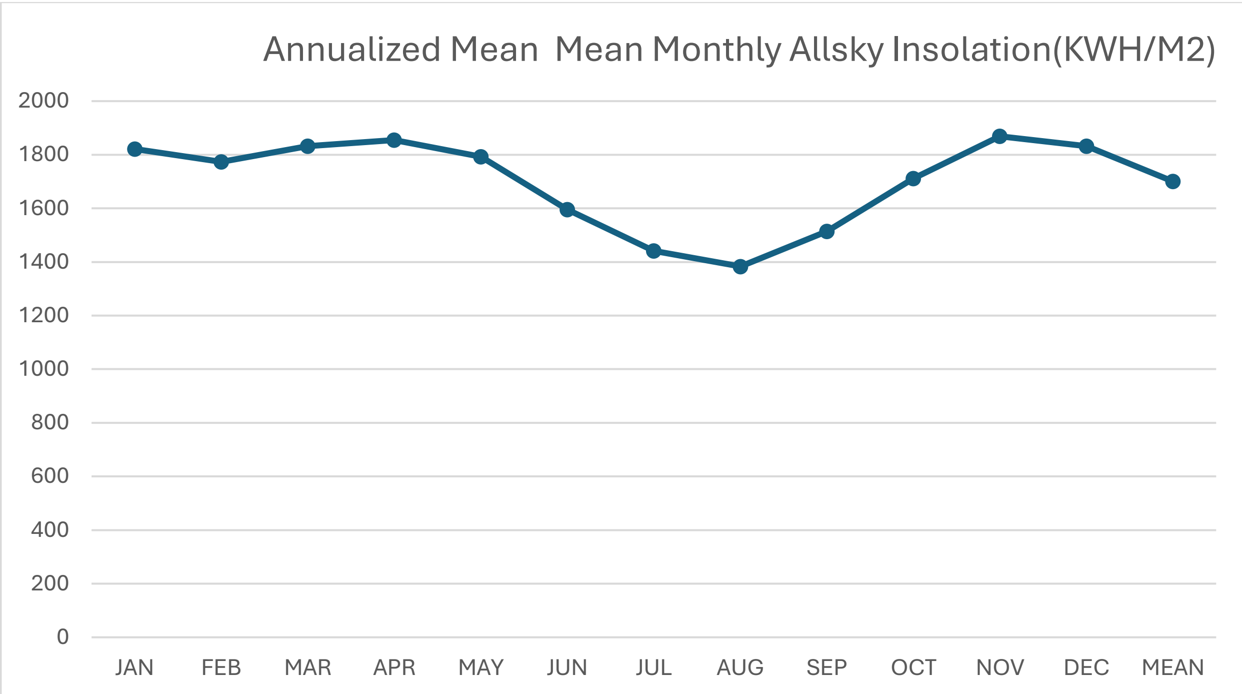

Fig. 5.3: annualized mean monthly all-sky insolation

As presented in Figures 5.1, 5.2, and 5.3, Southwest Nigeria is all–year suitable for STP and with excellent Hight Temperature Thermal Energy Storage (HTTES) systems, a much lower electricity price compared to the values presented, and at a lesser payback period of 5year to 10years on not more than 8% discount rate is the conservative likelihood.

6.0. Conclusion and Recommendation

STP is a very viable power generation technology for powering mini–grids in Southwest Nigeria as a short, medium, and long-term solution to energy poverty in line with the United Nations' Social Development Goals (SDG7) and climate change objectives, being a Clean Development Mechanism that will see to several direct and indirect benefits in the region.

By the results of this research, Southwest Nigeria needs to be properly planned with the best convenient sites selected in respect of the requisite Environmental and Social Impact Assessment (ESIA) for STP plant construction and installation, irrespective of technology types.

In addition, solar-thermal technology can be integrated with existing conventional power plants, especially thermal stations and combined cycle steam turbine generation, by the use of solar towers or parabolic troughs to partially heat or supply part of the system. This will help improve the reliability and redundancy of power generation systems, especially regarding the problems of frequent gas delivery interruptions, pipeline infrastructure deficit, upstream oil and gas vandalism, limited reserves, safety, and rising cost of gas.

There is a need for the establishment of regional renewable energy data gathering, both from ground and satellite recording, to enhance and engender research and development efforts for accurate information and physical planning for short, medium, and long-term energy programs that are based on local renewable energy resources.

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